RIEN SANS PEINE

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LECTURES

ON

MINING

DELIVERED

AT THE SCHOOL OF MINES, PARIS

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LECTURES

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AT THE SCHOOL OF MINES, PARIS

BY

J. CALLON

INSPECTOR GENERAL OF MINES

TRANSLATED AT THE AUTHOR'S REQUEST

BY

W. GALLOWAY, AND C. LE NEVE FOSTER, D.Sc.

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LECTURES

ON

MINING.

CHAPTER XII.

EXAMPLES OF UNDERGROUND WORKINGS.

(339) In the preceding chapter we discussed the methods which may be adopted for working lodes of various sizes, masses, and, lastly, coal seams, or typical stratified deposits.

We learnt that when a deposit is sufficiently extensive to be worked permanently, the empty spaces left by the removal of the mineral cannot, as a rule, be left unfilled. The conclusion was forced upon us that either the empty spaces should be filled up, or the roof should be allowed to fall in; or, finally, the idea of removing all the mineral should be given up. We therefore arranged the methods of working under three heads, as follows:

Filling-up methods. The empty spaces produced by the workings are packed with sterile rock as fast as the mineral is removed. The stuff for "stowing" is derived from the workings themselves, or it is quarried specially underground, or it is brought down from the surface.

Methods in which pillars are cut out, and subsequently removed. A network of pillars or large blocks is first of all formed by driving suitable galleries; the pillars are then removed, proceeding backwards from the boundary, and the roof is allowed to fall in.

Lastly, methods of working by pillars and chambers, or by galleries and permanent pillars. In this last system the working period is considered to be at an end as soon as the galleries have been driven.

The characteristic feature of the methods comprised in the first class is, that they allow *as complete a removal of the mineral as may be thought desirable,* whilst at the same time they cause a minimum amount of movement in the superincumbent strata, and so reduce the surface damages and the quantity of water which finds its way into the workings.

The methods comprised in the second class are distinguished by their small cost. This, however, is sometimes more than counterbalanced by waste of the mineral itself, either as regards its quality or quantity, and by the effects of subsidences of the surface, which involve larger payments for surface damages, greater costs for drainage, and occasionally the danger of spontaneous fires underground.

Lastly, though the methods comprised in the third class are supposed to prevent any movements of the overlying rocks, they have one radical defect; viz., that of causing a considerable loss of mineral, and of consequently being unsuitable even for moderately rich deposits. As a rule, therefore, methods of the first or second class should be substituted for them, save where the mineral wrought is exceedingly abundant or of very little intrinsic value.

(340) In considering deposits with reference to their mode of occurrence in the bosom of the earth, we must distinguish them as *beds, veins,* and *masses.* The two former may be described geometrically as large lenticular masses of mineral, inclined in various ways, having two dimensions indefinite compared with the third, which is essentially limited (No. **9**). *Masses* properly so-called, on the other hand, may have the same origin as beds or veins, but they do not fulfil the same simple geometrical definition.

In the case of beds and veins, the thickness must be taken into account, and we distinguish those of *ordinary* and *extraordinary thickness* (*width* in the case of veins).

These two expressions do not correspond to a certain number of

feet, which can be stated *à priori* with absolute exactness. What we mean by *ordinary thickness* (*width*) is a dimension which is *comparable* to the height (or width) at which the working places can be kept open, at right angles to the plane of the deposit, under the conditions of the locality. By this we mean an amount smaller than, equal to, or at most slightly greater than this dimension, so that the whole thickness of the mineral is removed in one operation along the plane of the lenticular mass.

Veins of ordinary width are worked by overhand or underhand stopes, and beds of ordinary thickness by the long-wall system, or by the pillar and stall system with all its varieties.

The *thickness* is *extraordinary* when the local conditions are such, that the whole thickness of the deposit cannot be removed in one operation in the plane of the lenticular mass.

Veins and beds coming under this category, as well as masses, are generally worked according to one of the preceding methods, by subdividing the deposit into several parts, which are attacked successively, the entire thickness of each subdivision being removed in one operation. The most natural way of subdividing is to suppose a number of parallel planes forming a series of slices; the planes of division may be either horizontal, or parallel to the stratification, or else vertical.

The first arrangement is suitable for highly inclined deposits, or for masses presenting no appearance of stratification, or pronounced jointing (*cleat*).

In a general way the *crosscut method* allows us to work by any of the three systems mentioned in the preceding paragraph, and is employed in practice with or without filling up, and with or without pillar working.

Where the empty spaces are filled up we have the crosscut method properly so called; but in reality we ought to make a distinction between the crosscut method with *filling up*, the crosscut method with *pillar work*, and the crosscut method with *chambers and permanent pillars*. All three systems may be seen in practice, although the first is the most common.

The second arrangement (that is to say, the division of the deposit into slices parallel to the stratification) usually facilitates

the "getting," and is occasionally favourable for an increased daily output, because a more extensive slice can be taken than where crosscuts are used. However, this method cannot be employed where the dip is high. We shall call this plan the *slice method,* recollecting, in order to distinguish it from the crosscut method, that the slices are taken parallel to the stratification.

The slice method does not exclude the use of stowing (Rive-de-Gier method), nor pillar working (Blanzy method), nor the system of chambers and permanent pillars, which the "old men" often adopted for thick seams near their outcrop.

Finally, the third or *vertical method* is merely the crosscut method with filling up, in which all the slices composing a floor or story are removed at once *in each locality,* so that the whole thickness of the deposit may be removed in one place whilst in the immediate vicinity operations are being carried on in the first or second slice.

The object of this arrangement is to prevent any slice from being long exposed to the effects of the subsidence, which necessarily ensues as the filling up becomes gradually compressed.

(341) The choice of one of the above methods in any given case is a problem of the utmost importance, and one which requires a very careful examination before it can be properly solved.

Where the cost price per ton is the sole consideration, the methods of the second class are most advantageous, because, as compared with the first, they save all the expense of filling up, and by increasing the total output per acre, they reduce the amount payable to the sinking fund for the capital expended in starting the mine, and opening it out for working. The net cost per ton, however, is only *one* of the aspects of the question, and *not always the most important.* We insist upon this point because it is one of great consequence, and it is not always thoroughly understood. Directors of mines are often apt to consider the net cost per ton as their sole aim, and to believe that any reduction of it from one year to another is necessarily a step in advance. The accounts presented to the shareholders are generally drawn up in a manner likely to increase this tendency.

Thus for instance, in the accounts of railway companies, great prominence is given to the ratio between the expenditure and the gross receipts, and great credit is claimed if it has been reduced from 40 per cent. in one year to 39 in the next. This would be quite right if, in the two years under comparison, the same proportion of goods at different rates had been conveyed on the line; but it is misleading if in the second, year, for instance, that kind of goods traffic which yields the smallest amount of profit has increased the most, for then the ratio spoken of above may have become larger instead of smaller, and yet there will be real progress if the total net proceeds are augmented.

In other words, the criterion of progress in the case under consideration, is not the geometrical ratio between the gross receipts and the expenditure, but the increase of the arithmetical ratio between these two quantities; that is to say, the amount of the net proceeds. Consequently, there is always progress from one year to another, if we secure additional traffic which is in any way remunerative.

In the case of a mine, it sometimes appears desirable to put up with an increase in the price per ton in order to secure certain advantages; for instance, wages may be raised with the view of attracting foreign workmen, or more dead or exploratory work be carried on for the purpose of eventually increasing the output.

The right course to be pursued under such circumstances cannot be properly determined without taking into consideration the richness of the deposit, the nature of the mineral worked, and its commercial outlets.

We must turn to the remarks set forth in paragraphs **70** and **71**, and make up our minds to act differently with high-priced articles, which are produced in small quantities, from what we should with a cheap mineral, which may be worked regularly year after year and sold in the neighbourhood. In the first case a slight variation in the net cost per ton is only a secondary consideration compared with the advantage of extracting the mineral as *completely* and *speedily* as possible.

In the second case, where the profit per ton is usually small, the

net cost of production may be a matter of vital importance, in fact, if it goes up, it may render it impossible to work at a profit; we shall then be constrained to adopt a method of working which, though technically less perfect, will be commercially more economical, even if some mineral be left unwrought. It may also be found advisable to limit the output, for fear of overstocking the market, and losing by the consequent fall in price more than would be gained by the increased production, and by the economy in cost per ton which, within certain limits, is sure to accompany it.

These remarks show very plainly that the interest of the *lessee* of a mine is not necessarily the same as that of the *lessor* or proprietor of the minerals.

The interest of the mine itself, as an *immovable* property, may not always coincide with that of the holders of the *movable* securities constituting the shares of the mining company; or, in other words, the standpoint of the permanent shareholder who wishes the mine to be worked for the benefit of himself and of his children after him, is not necessarily the same as that of the temporary holder of a share which he has bought as a speculation with the hope of a rise. The latter, while waiting for a favourable moment to sell out, insists on having as large dividends as possible, without troubling himself about the burdens left by the past, or the possible requirements of the future.

It is necessary to weigh all the above considerations in choosing the best method of working a given deposit, and in settling the scale on which operations should be conducted.

These questions of method and scale of working are therefore very complicated, and require to be studied from a commercial and financial, as well as from a technical point of view. It is easy to understand that the various considerations will not all lead to the same conclusion; and it becomes necessary to seek a sort of mean or compromise, which may vary according to circumstances. What it comes to in general is this, that in any *bonâ fide* and properly conducted concern the guiding principle ought to be the *paternal* point of view. Nothing is more likely than this to ensure it permanent prosperity; and it seems to us that the best test of really good management is the amount of profit, reckoned

by the excess of the dividends over all the capital paid up, which remains after a company has been wound up.

This then, in our idea, is the theoretical result to which our efforts should tend from the beginning, though we must not expect to attain to it exactly, and for the following reasons: Sometimes we are prevented from reaching our goal by the shareholders themselves, who complain if the dividends are too small, or too long deferred; or, again, on account of technical or commercial changes which may take place in the course of working. These cannot easily be foreseen, even when close at hand, and they occasionally lead to a very abnormal state of things. Such was the case, for instance, with coal in the years 1872, 1873, and even 1874.

We need not dwell any longer on these matters, which distract our attention from the technical part of the subject, which is our chief object at the present time; and, in order to complete the general information contained in the preceding chapter, we will proceed to describe some examples of workings in which the different methods are applied. We shall also call attention to any details or special variations rendered requisite by the peculiar conditions of the example under consideration.

(342) We shall divide these examples as follows:

In the first place, we shall treat cases of working thin seams of coal or mineral veins of ordinary thickness; that is to say, deposits which are worked with *filling-up*, and where the whole thickness is removed in one operation.

Secondly, we shall take examples of coal seams of medium thickness worked without stowing, or seams of all thicknesses lying almost horizontal, but worked away in one operation; *i.e.* without being divided into slices.

Thirdly, we shall have to consider the cases where the conditions are analogous to those of thick seams slightly inclined, which we divide *into slices parallel to the stratification.*

Lastly, come such deposits as very wide lodes, masses, and thick, highly-inclined seams, which are worked in *horizontal slices* according to all the different varieties of the crosscut method.

We may assume that every variety of mineral deposit that can be worked may be included under one or other of the above heads, and this will be proved conclusively when we have examined the proposed examples.

(343) As instances of the first class we will take the copper-slate mines of the Mansfeld district, and the underground quarries of thin seams of stone near Paris.

The copper-slate of Mansfeld forms a well-marked geological horizon in the Permian rocks below the Zechstein. The metalliferous part of the bed is only about 1 ft. ($0^{m}\cdot30$) thick, with a barren undercut of 4 in. ($0^{m}\cdot10$). The working-places are made about 2 ft. ($0^{m}\cdot60$) high by taking down about 8 in. ($0^{m}\cdot20$) of the roof, and more than enough refuse is so produced to fill the empty spaces; in fact, some of it has to be drawn to the surface. We have here a case similar to that of thin seams of coal (Nos. 285 *et seq.*), and the long-wall method of working is adopted. (Fig. 236.)

First of all a mother-gate is driven and partly stowed, leaving a principal hauling road 6 ft. 6 in. (2 metres) high, with an air-way 4 ft. 3 in. ($1^{m}\cdot30$) high on the rise side, and a water-way of about the same height on the dip side. (Fig. 237.)

As the mother-gate advances, a series of contiguous walls about 65 yards (60 metres) long are taken on the rise side, and the empty spaces are stowed behind, leaving a few roads, which come up to different points of the face.

The walls are carried neither along the dip nor along the strike, but usually diagonally, so as to obtain the most favourable gradients for tramming, and also for the purpose of carrying off at once into the stowing the water soaking out of the face, which would render the work of the hewers still more uncomfortable if the faces were taken parallel to the dip, as it would run down along the face itself.

Each wall or face 65 yards long requires a score of hewers.

The transport from the working faces to the principal tramroads is exceedingly laborious, because the roadways through the stowing are kept very low to save the cost of cutting away the roof, and sending the deads to the surface.

The so-called *thin beds* of stone in the neighbourhood of Paris are those whose thickness is less than the height necessary for the roadways. A true holing is made in some softish marl under the stone, and carried in for a depth of 6 or 7 feet (2 metres or more,) a few small pillars being left here and there to support the stone. The next operation consists in making a series of vertical cuts, and the stone is finally brought down by driving in wedges along the planes of bedding at the top.

It is usual to take a series of walls or faces from 13 to 22 yards (12 to 20 metres) long. (Fig. 238.) The empty spaces are packed by shovelling in the *débris* from the holing and vertical cuts, or else the strongest pieces are picked out from the rubbish and built into pillars. These are put up at intervals, principally on each side of the gallery or road, which is kept up in the stowing for the purpose of drawing away the stone from each face. The roadways lead either to the drawing shaft, or else directly to the surface, if the bed is worked on the side of a hill. In the latter case they are often made high enough for carts to go in and be loaded at the working faces.

In these two instances, therefore, the same method has been applied as that which is used for thin seams of coal. A similar mode of mining is adopted for deposits of clay ironstone, which occurs in the form of nodules and more or less continuous flat lenticular masses in the shales of the Coal Measures.

(344) We now come to the second class; viz., deposits removed in one operation, without previous subdivision into slices, by methods similar to those adopted for coal-seams of medium thickness. Examples of such workings are readily found; but we shall merely mention the underground quarries of building stone and gypsum near Paris, and deposits of stratified iron ore and rock-salt.

The stone quarries near Paris included in this class are locally known as "carrières de *haute masse*," on account of the thickness of the beds worked. The method of working consists in leaving solid pillars (*piliers tournés*) in contradistinction to the built-up pillars (*piliers à bras*) spoken of in the preceding paragraphs. The

latter are constructed by the quarrymen with the materials used for filling-up; the former are left in the course of working. As the quarries of thick stone furnish very little in the way of *débris*, as no materials for packing the empty spaces are brought in from the surface, and as it is expedient to prevent subsidences of the surface, the driving of the galleries constitutes the whole of the working. This plan may, therefore, be called the method by galleries and permanent pillars.

The galleries are made as wide, and the pillars as narrow, as local circumstances will permit.

If we denote by B and B′ (fig. 239) the width and length of the pillars, and by A and A′ the corresponding dimensions of the galleries, so that $A+B$ and $A'+B'$ shall be the distances between the homologous angles of two consecutive pillars, it is easy to see that the portion of the deposit removed is represented by the expression—

$$\frac{A}{A+B}+\frac{A'}{A'+B'}\times\frac{B}{A+B}=\frac{AA'+AB'+A'B}{(A+B)(A'+B')}$$

The portion of mineral left in the pillars will be—

$$\frac{B'}{A'+B'}\times\frac{B}{A+B}=\frac{BB'}{(A+B)(A'+B')}$$

The sum of these two quantities is equal to unity.

If, for the sake of argument, we take $A=A'$ and $B=B'$, and $A=B$, then the first quantity becomes $\frac{3A^2}{4A^2}=\frac{3}{4}$, and the second $\frac{A^2}{4A^2}=\frac{1}{4}$; one quarter of the mass is consequently lost, as is at once seen in this simple case.

If the beds are strong enough to allow us to take $A=2B$, retaining the relation $A=A'$, and $B=B'$, the above ratios become respectively $\frac{4B^2+2B^2+2B^2}{9B^2}=\frac{8}{9}$ and $\frac{B^2}{9B^2}=\frac{1}{9}$; in other words, only *one-ninth* of the bed is lost in the form of pillars.

Under these conditions, that is to say, when the bed itself is sufficiently solid and the roof sufficiently strong, there would evidently be no advantage in endeavouring to remove this last ninth. If we were to remove the pillars without stowing, the surface would fall in, whilst, on the other hand, packing the empty

spaces would be too expensive; besides, in either case, the stone obtained would be more or less crushed by the pressure, and therefore of inferior quality.

The expediency of using the method under consideration increases with the strength of the rock and the possibility of making wide galleries and narrow pillars.

We have supposed that the galleries were driven in two directions at right angles to one another, as shown in fig. 239; but this arrangement may be varied, as in fig. 240, without altering the ratio between the pillars and the amount excavated. In this second plan the pillars are arranged in rows, so that those of one row are opposite the empty spaces of the two adjoining rows.

The first arrangement is called *quincuncial*, the second the *chess-board* plan, because a regular chess-board would be produced, supposing the pillars to be square and equal to the spaces, if the rows were brought close together by leaving out the long galleries. The latter arrangement is safer than the quincuncial, because it affords more security against falls of roof when there are little *slips* or *slides* (in French, *fils* or *filières*). These are long fractures which affect not only stone itself, but also the roof and floor. They are true narrow faults, in fact, filled with clayey matter, but not exhibiting much vertical shifting; in a given quarry their direction is pretty well constant. The long galleries are driven at right angles to this direction, and then by the chess-board plan any slide is sure to meet with the pillars of the odd or even rows.

The gypsum quarries of the departments of Seine, Seine-et-Oise, and Seine-et-Marne are worked by the system just described. As is well known, operations are carried out on a very extensive scale, and the produce of these quarries, besides supplying Paris and a part of France, is exported to England, and even to America.

Where the gypseous formation is well developed, the principal bed is from 52 to 65 ft. thick (16 to 20 metres).

The working places are arranged in chess-board fashion, as described above; the pillars are 10 ft. (3 metres) long at the base, and the *stalls* 16 ft. wide (5 metres). Where a slide is met with these dimensions are altered, and the pillars are then left so as to catch it along their axis. The galleries or stalls are not

carried up to the very top of the bed, but a roof about 3 feet (1 metre) thick is left to support the green marls above the gypsum, and a somewhat greater thickness is left on the floor so as to brace together the pillars at the base and prevent the floor from rising (*creeping*). The workings are thus kept firm, and the floor is preserved in good condition for haulage.

The sides of the stalls are cut perpendicularly for the first third of their height from the floor, and then they are gradually contracted until at the roof they are only 8 ft. ($2^m.50$) apart. These stalls are formed by driving a heading at the top and then cutting away a series of underhand stopes.

It is easy to calculate approximately the quantity of stuff derived from the stalls and left behind in the pillars. Neglecting the curvature of the arch and the layer of gypsum left in the roof and floor, we will denote by A, B and A′, B′, as before, the widths of the stalls and pillars, and by H, the height of the stalls. We evidently have the relation:

$$A = A' = \tfrac{1}{3}H \times 5m. + \tfrac{2}{3}H \times \frac{5 + 2{\cdot}50}{2} = \tfrac{1}{3}H \times 12^m{\cdot}50$$

$$B = B' \doteq \tfrac{1}{3}H \times 3m. + \tfrac{2}{3}H \times \frac{3 + 5{\cdot}50}{2} = \tfrac{1}{3}H \times 11^m{\cdot}50$$

The general formula given above, viz., $\frac{AA' + AB' + A'B}{(A + B)(A' + B')}$ becomes

$$\frac{A^2 + 2AB}{(A + B)^2}, \text{ when } A = A' \text{ and } B = B', \text{ and}$$

$$\frac{A^2 + 2AB}{(A + B)^2} = \frac{(12{\cdot}50)^2 + 2 \times 12{\cdot}50 \times 11{\cdot}50}{(12{\cdot}50 + 11{\cdot}50)^2} = \frac{443{\cdot}75}{576} = 0{\cdot}77.$$

In like manner, with the conjugate formula we have—

$$\frac{BB'}{(A + B)(A' + B')} = \frac{B^2}{(A + B)^2} = \frac{(11{\cdot}50)^2}{(12{\cdot}50 + 11{\cdot}50)^2} = \frac{132{\cdot}25}{576} = 0{\cdot}23.$$

The conclusion to be drawn from these two numbers is, that, taking into consideration the local conditions, the method of working *is not very wasteful*, and that probably it would be *economically impossible* to replace it by any *technically more perfect* method, such as subdividing it into slices, and working with stowing or removing the pillars. This economic impossibility is caused by competition, which keeps down the profit of the mine-owners, the

high price which would have to be paid for materials for filling up, and, lastly, the great value of the land which would be destroyed either in procuring stowing materials, or by subsidence of the surface if they were not used.

This case is therefore an instance of the thick deposits referred to in No. **283**, which do not afford any stuff for packing the empty spaces, and are too poor to pay for its being procured specially.

Figures 241 and 242 are vertical sections, made, firstly, at right angles to the continuous galleries, or along the line A B of figure 240; and, secondly, parallel to the line C D of the same figure.

(**345**) Iron ore is frequently met with in rocks of very different geological ages, in the form of beds of various thicknesses, and sometimes of considerable extent, with all the regularity of a seam of coal.

Such, for instance, is the hydrated oxide of iron mentioned in No. **41**, which forms a well-defined geological horizon, not only in the east of France and the Grand Duchy of Luxemburg, but also in the Department of the Aveyron; and in England there is the great bed of iron ore in the Cleveland district.

Deposits of this kind are worked by the system of long blocks, described in Nos. **297** *et seq.* (fig. 217). The original galleries are made 13 to 16 ft. (4 to 5 metres) wide, and the blocks between them about 11 yards (10 metres).

The blocks are then removed by a series of crosscuts, either immediately contiguous or separated by a narrow pillar of ore, as has been explained in detail in No. **301.** Sometimes the *English plan* is adopted, of driving a series of narrow galleries, 20 to 30 yards apart, and then working away the intervening blocks by very wide stalls, separated by narrow pillars, 5 ft. to 6 ft. 6 in. ($1^{m}.50$ to 2 metres) wide, which are looked upon as lost. The stalls are first of all very narrow, and widen out gradually; at each extremity pillars about 4 yards wide are left to protect the main roads. While sacrificing a small part of the ore, this system is favourable for affording large lumps, for economizing timber, and for rendering the workings safe. A plan of it is given in figure 243. It must be understood that when a roadway is abandoned as much ore as

possible is "robbed" from the two 13 ft. (4 metres) protecting pillars right and left, one of which is quite continuous, and the other pierced by little drifts which afford access to the stalls (fig. 243).

Beds of ore may be worked very cheaply in this way provided that the roof is good and the ore easily broken.

Instances might be cited of favourably situated works where iron ore is delivered at the top of the blast furnace at less than 1s. 7½d. per ton (2 francs per metric ton). This is not possible unless the mine is worked by an adit level, the mouth of which is close to the furnace.

(346) Beds of rock-salt, varying in thickness and quality, are found in many geological formations, but especially in the Keuper or Variegated Marls of France and England. The salt is obtained by methods more or less analogous to those just described for the thick stone and gypsum beds near Paris.

At Dieuze, for instance, a salt bed 16 ft. (5 metres) thick is worked by stalls 20 ft. (6 metres) wide, of the shape and dimensions shown by figure 244; pillars 14 ft. to 16 ft. ($4^m \cdot 50$ to 5m.) square are left to support the roof.

At Varangeville, near Nancy, workings were carried on for many years in a bed 65 ft. (20 metres) thick, of which the bottom 16 to 20 ft. (5 to 6 metres) are pure enough to supply a large proportion of rock-salt. The upper part, on the contrary, is so much mixed with clay that the salt has to be dissolved out, and separated by evaporation.

The rock-salt was obtained by working the pure part by a system of stalls and pillars, the stalls being 26 to 30 ft. (8 to 9 metres) wide, and 18 ft. ($5^m \cdot 50$) high, and the pillars 20 ft. (6 metres) on the side (fig. 245). A thickness of 20 in. to 2 ft. of rock-salt was left in the floor. The mineral was *got* either with the aid of the pick and blasting, or else vertical cuts, 6 ft. to 10 ft. (2 to 3 metres) deep, were made by means of water, leaving blocks 6 ft. 6 in. (2 metres) wide, which were readily removed afterwards. The water for this purpose was brought into the mine by a 4-in. (10 centimetres) cast-iron main, and was distributed to the various

working-places by cast-iron pipes decreasing from 3 to 2 in. ($0^m.08$ to $0^m.05$), and finally to 1¼-in. ($0^m.03$); the actual cuts were made by means of tubes 5½ in. ($0^m.14$) long, with 5 or 6 little holes, of about $\frac{1}{25}$ in. in diameter, pierced across them, which acted like the rose of a watering-pot. The speed of cutting depended on the quantity of water ejected against the upper part of the cut. The saturation increased as the quantity of water running down the sides of the cut was diminished, so that there was a close relation between the monthly progress and the degree of saturation.

The usual plan was to arrange so that the water should be half-saturated, and by so doing it was possible to keep up the rate of driving and at the same time prevent the brine from being too weak; for this fault would have involved extra expense at the surface, either for saturating the brine by lumps of impure salt, or for evaporating it directly.

When this work was finished in any particular panel the roof of the stalls was stripped till they were 55 ft. (17 metres) high, which left about 10 ft. (3 metres) of salt still standing. We have already stated that the upper part of the bed is so much mixed with earth that it is only available for the production of refined salt. If this impure salt had been brought to the surface it would have been necessary to dissolve it in water, and then evaporate the brine after allowing it to settle. It naturally appeared an economical plan to dissolve it *in situ*, and pump the brine to the surface, instead of breaking the ground with the pick, raising it in kibbles to the surface, and dissolving it there. The network of pipes described above was used for this work also. A light scaffold, running on wheels, made of the width and height to suit the galleries, was brought into each working-place, and 36 T-shaped tubes, 5½ inches long, were fixed at the top, through which water was forced against the whole width of the upper part of the face. These T tubes were fixed on to a pipe connected with the water main by an indiarubber hose.

This is the system which was introduced at the Varangeville Salt Mines by the manager, M. Pfetsch, and worked successfully for several years. It was evidently very economical for extracting the rock-salt, and especially for working the salt marls, because it

reduced the cost of labour by one-half in the first case, and brought it down to almost nothing in the second.

It required, however, for a given monthly output, a greater extent of workings to be kept open than would have been necessary with the ordinary processes of mining, and the difference increased in proportion as it was desired to raise the saturation of the brine.

The more or less saturated brine was collected at the bottom of each stall by a wooden *launder*, which carried it to a cistern, from whence it was pumped to the surface. Before evaporating it, the brine was rendered stronger by putting in lumps of impure rock-salt.

Figure 246 shows how the stripping process was conducted. The outline of the face should be noticed. It is due to the solvent action of the water diminishing as it runs down the face on which it is acting.

Such was the method of working pursued for fifteen years; but recent events have shown that the pillars were too small, and the stalls too wide, to ensure the safety of the mine permanently, as long as the solvent process was resorted to.

The marl of the floor, which was always more or less salt-bearing, became gradually softened by the semi-saturated brine which was not completely carried off by the launders; and finally losing its solidity, began to swell up, or rather the pillars began to sink into it. The sinking went on at first very slowly for several years; but it gradually became more marked, and finally there was a sudden loss of equilibrium, which caused an instantaneous subsidence, manifested at the surface by a depression of 10 feet over an area of 17 acres (7 hectares). The subsidence was so sudden that a violent current of air was produced in the workings, which rushed up the pit, carrying up the cages, and blew off the roof at the top. The mine had to be abandoned, and new workings were commenced in other places.

It is very clear that this falling in might have been avoided, or at all events postponed for a long time, if the pillars had been made wider, the galleries narrower, and an ample bed of rock-salt left on the floor; besides all this, arrangements should have been made to prevent the semi-saturated brine from coming too much

in contact with the floor before being collected into the launders which conveyed it to the pumps.

(347) As an instance of a mine belonging to the third class (No. 342), we will cite the underground chalk pits of the neighbourhood of Paris. The deposit may be looked upon as a horizontal bed, or rather a series of superposed horizontal beds, affording an almost indefinite thickness. It is practically a deposit unlimited in all directions, furnishing a product of very little value, and not supplying any rubbish for stowing.

The low price of the produce, and its extreme abundance compared with the demand for it in commerce, forbid the use of stowing or any method of pillar working which would cause the ground to *cave in*. We are thus led naturally to use the method of superposed pillars and chambers without any subsequent pillar working.

The mines are worked in three floors or stories, permanent pillars being left in each. They are arranged so that the pillars of one story shall be directly above the pillars of the one underneath, and the same with the chambers; and besides, care is taken to diminish the width of the galleries, and increase the size of the pillars and the thickness of the intervening floor, as successive stories are worked one under the other.

The following series is formed:

1st STORY. Galleries, 6½ yards by 6½ yards (6 metres); pillars, 13 ft. by 13 ft. (4 metres).

Solid floor, 10 ft. (3 metres).

2nd STORY. Galleries, 5½ yards by 5½ yards (5 metres); pillars, 5½ yards by 5½ yards.

Solid floor, 13 ft. (4 metres.)

3rd STORY. Galleries, 13 ft. by 13 ft.; pillars, 6½ yards by 6½ yards.

The nature of the ground renders it necessary to cut the roof into a semicircular arch. The system of working is shown by fig. 247, which is clearly analogous to that represented in fig. 212, plate 34. It sometimes happens that some beds are rendered much firmer by the presence of nodules of flint; and when one of

these beds can be taken for a roof, the top of the stalls can be cut in the same shape as that adopted in the gypsum quarries.

Chalk is so soft that it is generally broken with great ease; but its want of solidity and elasticity cause falls to occur *without giving any warning*, and often on a large scale. This renders great care requisite in breaking it down. There have been cases of entire quarries being crushed in instantaneously, producing violent currents of air like those alluded to in connection with the Varangeville Salt Mine.

(348) We now come to the fourth class, which includes deposits which can be worked by horizontal slices, or, in other words, by the crosscut method, either with stowing or pillar working, or with pillars and chambers, and no pillar working. These deposits present so many peculiarities, that it is necessary for us to bring forward several examples.

As an instance of the crosscut method properly so called, or crosscut method with filling up, we shall take Almaden Mine, in Spain.

The crosscut method, combined with pillar working, is applied at the Stahlberg Iron Mine, to the calamine deposits of Silesia, to the alum shales of the Liége district, &c.

Finally, as an example of superposed pillars and chambers without pillar working, we shall cite the case of the salt marls of Salzburg, It is true that the solubility of the useful product imparts a special character to the workings; but this does not modify the fundamental principle of the method.

(349) The celebrated mine of Almaden, in Spain, furnished the greater part of the quicksilver consumed in the world until the New Almaden Mine was opened out in California. Figure 248, taken from M. Ezquerra del Baio's *Laboreo de Minas*, represents a horizontal section of the deposit taken along the third story, and shows that there are three distinct and nearly parallel masses. They are known for a distance of about 200 yards (180 metres) along the strike, and have a total thickness of 82 ft. (25 metres) spread through a belt of rock 164 ft. (50 metres) thiok. The

deposits are nearly vertical, and appear to increase in length and thickness with the depth. The dip is N.E., and as the southern deposit underlies most, it seems as if they would all come together lower down.

Although the deposits are so inextensive along the strike, and though the total depth of the workings at the present day does not exceed 191 fathoms (350 metres), this mine has supplied a total of about 45,000 tons of quicksilver during the last two centuries. At the prices of a few years ago (4s. 4d. per lb. or 12 frs. per kilo.) this would represent more than twenty-one millions sterling (540 million francs); and even at present rates it represents about one-half that amount. The value of the output of the best years has reached nearly half a million sterling (12 million francs).

The ore yields on an average, when treated on a large scale, 8 per cent. of quicksilver. The cubic yard in place, supposed to weigh 37·6 cwt. (cubic metre 2½ metric tons), would therefore yield 3 cwt. of quicksilver (200 kilos. per cubic metre), or the enormous value of £36 even at the low prices of the last few years (1200 francs per cubic metre).

Such richness renders it imperatively necessary that none of the ore should be lost; and this need of great care may be expressed in figures by the fact that, if we leave out of account the cost of the metallurgical treatment, the owners of the mine can afford to pay 7s. 2d. *extra cost* per cubic yard (12 francs per cubic metre) rather than lose 1 per cent. of the weight of the ore.

The method of working consists in sinking winzes about 13½ fathoms (25 metres) deep, either in the footwall or in the lode itself if the ground is easier. They are made 11 ft. (3^m·40) long by 8 ft. (2^m·50) across.

Underhand or overhand stopes are then taken off from the sides of the winze, and in this way a slice parallel to the walls is removed for a thickness of 8 ft. (2^m·50) and height of 13½ fathoms (25 metres). Thanks to the firmness of the walls and ore itself the openings can be kept secure by occasional props, or by leaving a few pillars of ore, or, finally, by building a few light and flattish arches of masonry stretching from one wall of the excavation to the other. As the stopes proceed further and further away

from the winze a series of crosscuts, 11 ft. ($3^m.40$) wide, are driven from the foot-wall to the hanging-wall, leaving pillars of the same width.

The crosscuts serve for the construction of arches from one wall to another. They are carefully built of hard sandstone quarried near the mouth of the main shaft, or else of bricks specially made in the form of *voussoirs.* The arches are 11 ft. ($3^m.40$) wide and 2 ft. 9 in. ($0^m.85$) thick. The chord is taken at right angles to the line of dip.

Each arch serves to support a pillar of masonry, which is built up at the same rate as the miners rip down the roof of the crosscut. The space between the roof of the crosscut and the top of the masonry is never more than 5 ft. 6 in. ($1^m.70$).

The roof of the crosscut is ripped down slowly, and work is frequently stopped for a time so as to give the mortar of each portion of the masonry time to set, and thus prevent any ore from sticking to it. This process is carried on until the ore is excavated for the entire height of the winze, and the column of masonry replacing it is joined to the arch of the winze above. Sometimes an arch is built midway up the column so as to take off the weight from the bearing arch below.

When a series of these masonry columns has been built for a certain distance, half the ore has been removed. The remainder is obtained by attacking the intermediate pillars or *reserves* of ore by a second series of crosscuts, which are not, however, filled up with masonry like the first.

Finally, after all the ore has been removed, the old workings present a series of high walls 11 ft. ($3^m.40$) wide arranged along the dip, and separated by empty spaces of the same width.

The levels, which have to be maintained for the conveyance of the mineral underground, are formed by leaving openings 7 ft. ($2^m.10$) wide by 8 ft. ($2^m.50$) high when the masonry is being put in. The empty spaces between the columns of masonry are crossed by little bridges.

Similar openings, or larger ones properly arched, are left in the body of the masonry also for the purpose of lightening it.

This method of working is practically a crosscut method with

filling up; but instead of the empty spaces being stowed with continuous horizontal sheets of rubbish, they are only partially filled by masonry, which is built up in the form of nearly vertical columns. (No. 340.)

The object of this system is to prevent the general subsidence which results from the stowing materials gradually becoming packed together in the ordinary method of horizontal slices. It is evidently well adapted for a locality where prop-timber is extremely rare, and for a mine where the great value of the ore makes it requisite to prevent any loss, either in the form of occasional supporting pillars, or as dust which would become mixed with any loose filling up.

It would not, however, always be possible to remove a slice along the foot-wall or in the deposit itself, in the manner described, if the walls and the ore itself were less firm than at Almaden. For preventing any general disturbance of the mass it is a good plan never to have any great length of stopes, but to keep the *wall* or *end of ground* almost vertical, and if necessary to stope away from only one side of the winze at a time.

If the rock and ore were less firm than at Almaden, it would be advisable to push on only one set of overhand stopes; that is to say, to begin by removing the ore at the bottom of the winze only, and to drive successive crosscuts as the first stope advanced. The upper part would be stoped away in due course, and so render it easier to drive both series of crosscuts.

The system of working is represented in figure 249, and it is further described in the explanation of the plates.

It has often happened that the pillars of ore have been left untouched for a long time, either because they were looked upon as reserves which should be husbanded, or because the ore could not be so easily got as that of the first series of pillars. We consider that this plan was wrong, and that it is best to remove every pillar as soon as it has been enclosed between two columns of masonry. It would also appear most simple to remove them by underhand stopes, whereas the first series of pillars are taken by overhand stopes, the miners standing on the masonry as it is gradually built up.

(350) The Stahlberg deposit has already been described in No. 53, and fig. 45 is a section of it borrowed from the Atlas of *La Richesse Minérale.* The ore is obtained by crosscuts and pillar-working as described in No. 282.

The system consists in driving galleries 20 ft. (6 metres) wide, and 23 ft. (7 metres) high, leaving pillars 13 ft. (4 metres) wide on each side, and a solid roof 10 to 13 ft. (3 to 4 metres) thick to separate them from the old pillar-workings above. Thanks to the firmness of the ore, these galleries can be driven without the slightest difficulty; but the pillars cannot be removed without great danger to the workmen, nor without great waste of the mineral. This ought not to be the case with an ore which is prized for its special qualities, and which seems destined to increase in value in consequence of the rapid extension of the Bessemer process.

(351) The alum shale near Liége forms a bed 52 to 65 ft. (16 to 20 metres) thick, dipping at an angle of 75°; it lies at the base of the Coal Measures, just above the Mountain Limestone. The shale is extracted by the crosscut method combined with pillar-working; slices are taken 20 ft. (6 metres) high, and they are removed in descending order.

Each slice requires a level along the foot-wall, which is driven as far as the boundaries of the proposed workings. It is carried 6 ft. 6 in. (2 metres) high, leaving consequently a solid roof of about 13 ft. A series of crosscuts, 6 ft. 6 in. (2 metres) wide, are driven from the floor to the roof, separated one from the other by pillars 3 ft. 3 in. (1 metre) wide. Figures 250, A B C are horizontal, transverse, and longitudinal sections, showing this mode of exploitation; these should be compared with fig. 229, which represents the plan of working a seam of coal in a similar manner.

When the crosscuts have been driven, the miners proceed to strip away what they can from the roof and side pillar. In order to facilitate the work, a little *rise* is put up into the *goaf* above, which lets down a quantity of rubbish and affords a solid basis for the men to stand on. The roof is stripped as far as possible, and the

side pillar is cut through here and there, so as not to sacrifice more of the mineral than is absolutely necessary.

(352) Workings are carried on in Upper Silesia on an irregular mass of calamine mixed with clay; its thickness varies at different levels from 0 to 33, 40, and even 50 ft. (10, 12 to 15 metres). The nature of the deposit is such that when the goaf is allowed time to pack together, it forms quite as good a roof as virgin ground itself.

The method of working is *analogous* to that described in the previous paragraph, but it exhibits certain differences which are rendered permissible by the nature of the ground just alluded to. The slices, which are taken in descending order, are only 6 feet 6 inches to 8 feet ($2^{m.}$ to $2^{m}.50$) high, and they are removed *immediately one under the other*, without any roof intervening. The drivages of a lower slice are carried on immediately below the crushed-in workings of the slice above. In the same way the successive crosscuts starting from the level on the foot-wall are contiguous. As soon as a crosscut is finished the timber is drawn, proceeding from the hanging-wall to the foot-wall, the roof crushes in at once, and the adjoining crosscut is then started. The crosscuts must be timbered so as to suit weak ground. (*See* No. **184**.)

In many cases only one *leg* is withdrawn; viz., the one near the *goaf*, whilst the *leg* near the solid ground is left, and sometimes even the *cap*. This plan helps to prevent the rubbish of the *goaf* from running into the next crosscut whilst it is being driven, but it uses up a great deal of timber.

We can form an exact idea of the workings by supposing that the intervening roof of 13 ft. (4 metres), in fig. 250, is omitted, as well as the pillar of 3 ft. 3 in. (1 metre) separating the *goaf* from each crosscut.

(353) As a final example we shall describe the method of working the salt marls of the Salzkammergut, a district situated on the borders of Styria and Salzburg; its salt deposits belong to the same group as those of Salzburg, the Tyrol, and Bavaria.

The massive deposits of this region appear to have no connec-

tion with those that have been formed by the evaporation of salt-water; on the contrary, they appear to depend on accidental dislocations of the strata which surround them. The masses are often of enormous dimensions; they are, for instance, 100 yards (100 metres) thick, half-a-mile (800 metres) or more long, and as no bottom has yet been reached their depth is practically unlimited. They are situated at such a height that the workings may be carried on for a long while hence above the level of the adjacent valleys, and consequently all the mines are worked by adits communicating with successive floors or stories.

Each story is 125 ft. (38 metres) high, and the workings are arranged as follows:

A crosscut adit is driven in from the hillside to intersect the deposit, and then a long level is carried along the strike with a series of crosscuts 65 to 90 yards (60 to 80 metres) or more apart; the crosscuts of the different stories are arranged so as to be almost exactly one above the other.

Narrow drivages are pushed out from these crosscuts for about 11 yards (10 metres), and are then opened out into great elliptical chambers with the minor axis about 22 yards (20 metres) long, and the major axis 44 to 66 yards (40 to 60 metres), as shown in figure 251.

The first operation in preparing the chambers is to form a network of drivages 5 or 6 ft. high, with intervening pillars 10 to 13 feet (3 to 4 metres) square. The drivages are carried on, and the chambers enlarged with the aid of water, by the methods described in No. **133**, which were invented in 1841 by M. Ramsauer, the manager of the mines. It takes about a year to prepare a chamber.

The mouth of the chamber is then closed by a dam made of clay mixed up with brine well rammed into the level, for a distance of 6½ yards (6 metres) and into two crosscuts driven right and left for a length of 13 ft. (4 metres). These three dams have to be heightened in proportion as the roof of the chamber rises. (*See* plan and section of the arrangement, fig. 252.) Water is brought in by an inclined *winze* from an upper story, and eats away the pillars and roof, leaving an elliptical chamber. The brine is drawn

off at pleasure by a pipe carried through the dam. The quantities of water that enter and leave the chambers are measured by a small gauging apparatus, which acts on the principle described in No. 64 of the *Cours des Machines.*

The galleries of each floor are provided with two pipes, one for bringing in fresh water to supply the chamber of the floor below, the other for carrying off the brine of the floor itself. As soon as the pillars of a chamber have been eaten away, the brine is drawn off and men are sent in to clear away the earthy residue on the floor, and throw it down to a lower level through a winze, which is then stopped up. We now come to the chamber work itself. This consists in dissolving away the roof, and the operation may be carried on either continuously or discontinuously.

The discontinuous process was for a long time the only one in use. It consisted in repeating successively two operations. Firstly, the chamber was filled with fresh water up to the very roof; and secondly, this water was allowed to dissolve the salt until it became quite saturated and ready to be drawn off.

It is easy to understand what takes place during these two operations. In the first part of the process the water eats away the sides, and the chamber is widened; but very soon the lower layers of the liquid become saturated, and cease to attack the sides, whilst the greatest solvent action takes place near the surface. The section of the chamber gradually becomes wider, and the amount of enlargement increases with the slowness with which the water is let in. However, as soon as the water touches the roof the widening action is no longer under control. The fresh water will now enter in proportion as the roof is dissolved away, and the quantity of water introduced is now regulated by the speed with which this solvent action proceeds. All that need be done is to keep the level of the water a few inches above that of the roof, so as to ensure the latter being always kept wetted. The water which attacks the roof is originally fresh, but it is gradually transformed into a strong brine.

During this second phase of the process the chamber is widened horizontally at the level of the water, but the main action is vertical. The rapidity with which the dissolving action proceeds

is favoured by gravity, which causes the clayey particles to fall, and thus constantly lays bare fresh surfaces of salt marl. It also draws the strong brine to the bottom as it gradually becomes saturated.

If we suppose that there is some definite ratio between the speeds of enlargement vertically and horizontally, a ratio which would diminish with the purity of the deposit, the chamber will be widened out in the form of an inverted cone. The inclination of its generatrix is determined by this ratio, and is consequently always greater than 45°, the angle which would be formed in the case of pure rock-salt. With fresh water this ratio must increase as the purity of the deposit diminishes, and for a deposit of a certain degree of purity it must increase with the degree of saturation of the brine. During the filling period therefore there is a general widening of the chamber, and the bell shape is less marked as the deposit is less pure. During the dissolving period the sides are eaten away at the water level, giving at first a regular slope of less than 45°, the exact angle varying inversely as the amount of impurities present; but finally the sides become more and more upright as the upper layers of the brine approach complete saturation.

Neglecting the widening produced in one operation, which is a small amount compared with the dimensions of the chamber, we may look upon the increase in volume as equal to the section of the chamber S, multiplied by the increase in height of the roof above the deposit of clay.

Let x represent the absolute increase in height of the roof; $\frac{1}{m}$ the richness of the deposit, or the volume of salt contained in one cubic metre; δ the specific gravity of common salt; δ' that of saturated brine (*i.e.* containing about 27 per cent. of salt); and lastly, h the original height of the chamber.

The weight of the salt dissolved is $\frac{1}{m} Sx\delta$.

The height of the mud in the bottom will have been raised by $(1 - \frac{1}{m})\, x$, neglecting the increase in bulk.

The volume of water is therefore—

$$S \times \left[h + x - \left(1 - \frac{1}{m}\right) x\right] = S\left(h + \frac{1}{m} x\right)$$

and the weight of the salt contained in it, neglecting the contraction which takes place during solution,

$$S\left(h+\frac{1}{m}x\right)0{\cdot}27\times\delta'$$

We consequently have the equation—

$$\frac{1}{m}Sx\delta=S\left(h+\frac{1}{m}x\right)0{\cdot}27\delta'$$

$$x=\frac{h\times 0{\cdot}27\delta'}{\frac{1}{m}\delta-\frac{1}{m}\times 0{\cdot}27\delta'}=\frac{0{\cdot}27\delta'}{\delta-0{\cdot}27\delta'}\times hm$$

This means that the increase in height of a chamber after a dissolving operation is in the direct ratio of the height before the operation, and in the inverse ratio of the richness of the deposit. We at once conclude that the height at the commencement should not be too small, and that the number of operations for a given height increases with the richness of the marl in salt.

There is also a relation between the height of the stories and the dimensions of the chambers, because when the chamber approaches the top of the story the roof must not be too wide to be thoroughly self-supporting.

Therefore the original diameter should be reduced as the height of the stories or the richness of the deposit increases. These are the principal conclusions we arrive at with regard to discontinuous solution.

In the case of continuous washing the operation goes on indefinitely as soon as the chamber is once filled, for fresh water is let in and brine drawn out in such proportions as to keep the chamber always full of brine of a certain degree of saturation. We have therefore the same state of things as exists in the last stage of the discontinuous process.

Figure 253 gives an idea of the outlines A B and A B′, such as are assumed by the sides of the chambers in the two methods of working. A B is the outline in the continuous, A B′ in the discontinuous system.

From the arguments adduced above, and from an examination of figure 253, we may conclude, in the case of continuous washing, that—

1. The chamber is widened regularly by the strong brine, instead

of there being successive periods of more active widening caused by the various fillings with water.

2. The chamber is being widened all through the continuous process to the same extent as it is at the very end of the discontinuous process.

3. Consequently, the chamber is very much less widened in the continuous than in the discontinuous process.

4. The roof is always supported by water, and so escapes the action of atmospheric agencies, which tend to make it scale off.

5. In consequence of the increased steepness of the sides of the chambers, it is possible considerably to reduce the size of the pillars between the chambers and the thickness of solid roof between two stories. In this way we obviate the principal defect of the method pursued (which is merely the crosscut method, with pillars and solid roof, without subsequent pillar working); viz., incomplete utilization of the deposit.

On the other hand, the marl is not acted on vertically nearly so quickly as in the discontinuous process; so that, in spite of time lost in successive fillings, the annual output of a chamber is much greater with discontinuous than with continuous washing. This is undoubtedly a defect. It is obviated, however, by having a larger number of chambers at work at a time; and in fact the defect mentioned is not considered to outweigh the advantages we have enumerated above, especially the more complete utilization of the deposit, the possibility of increasing the height of the stories, and so reducing the amount of dead work required for a given output.

The brine comes out of the chambers nearly saturated, and is received into reservoirs, where it is allowed to settle; the clear brine is carried in pipes to the works and evaporated in pans. These operations, however, have nothing to do with the actual mining, which is the subject we have to deal with here.

Such then is the method applied to a deposit in which the useful material is too impure to be sold in the state in which it occurs, and requires to be refined. As it must be dissolved in any case, it is easier to perform this operation *in situ*, and pump up the brine, than to break the stuff down in the ordinary way, and carry it to the works for solution.

There is economy in cost of breaking, as well as in that of haulage and winding, and, by the arrangements here adopted, quite as much of the deposit is utilized as would be by the system of superposed pillars and chambers without pillar working, carried on in the usual way.

(354) We may here mention that the solvent process is applied in another way, which dispenses with the arrangements and dead work described in the preceding paragraph.

A large bore hole is sunk to the deposit, and carried through it to its floor. If the overlying strata give out water, but not an overflowing supply, this water is allowed to run to the bottom of the hole; if not, water is brought in from the surface. A *bucket lift* is then fixed in the axis of the hole, and the wind-bore, clack-piece, and column of pumps are all arranged in the same vertical axis. The wind-bore should be dropped to the very bottom of the hole.

As the water gradually dissolves the salt, the most saturated layers sink to the bottom in virtue of their density, and consequently the pump always draws up the strongest brine. At the beginning the degree of saturation will depend on the speed of working the pump, and, with any given speed, it will gradually increase as a larger and larger amount of surface is laid bare and exposed to the solvent action of the water.

The continually increasing chamber which is thus formed extends away principally along the roof of the deposit, and especially towards the rise when the deposit is inclined.

This method of working is evidently very simple, and when a deposit has been explored solely by a bore-hole, the mere fixing of a pump reduces to a minimum the amount of capital to be expended before obtaining some returns. On the other hand, it may truly be said that we are working to a certain extent in the dark.

It may happen, for instance, that the roof of the salt bed is weak, and when the cavity becomes somewhat large it falls in, and creates subsidences seriously endangering the works built on the surface. Accidents of this kind have already occurred.

As it is impossible to regulate the extension of the chamber

called the *overburden*. Where the deposit crops out at the surface it is *nil;* but it may vary very much in thickness, if the mineral does not come to the surface.

The work of removing the overburden is called uncovering or baring the deposit. There is an intimate relation between the cost which may profitably be paid for uncovering and the value of the deposit laid bare; or, more correctly, between the *extra preliminary expense* that clearing away the overburden will entail, and the *subsequent saving in cost* of working which will be effected.

We know that the cost of working underground *increases but little* with the depth, whilst the output from a given area increases directly in proportion to the vertical thickness of the deposit. On the other hand, the cost of uncovering will generally be in proportion to the depth. It will, therefore, be readily understood that the principal point to be considered, in deciding whether a deposit is to be worked open or underground, is the ratio between the thickness of the overburden and the thickness of the mineral which will be laid bare.

In each particular case there is a limit, *above which* open working will be most economical, and *below which* it will be advantageous to have recourse to underground mining. This ratio will vary in each instance, and will have to be examined specially, as the advantages and disadvantages of each method must be carefully weighed.

(357) The principal advantages of open workings are—(1) Complete removal of the deposit without waste or danger of explosions; (2) Economy in cost of breaking, from being able to lay out large stopes, where the mineral can be "got" more readily than in narrow galleries.

As subsidiary advantages we have the fact of our requiring no timber, no stuff for filling up, and no expense for lighting; at all events, if the work is not pursued at night.

This last point may appear of very little importance; but it must not be neglected. An ordinary miner's lamp will burn 1½d. or 2d. worth of oil per shift, or 5 *per cent.* of the cost of the

underground labour, if the average wages are from 2s. 6d. to 3s. 4d. (3 to 4 francs).

We may make an attempt to reduce the above advantages into figures, and, under ordinary circumstances, the gain would be as follows:

On the *getting*, more than half the expense . .	say	10d. per ton
On the filling up, the entire expense (No. 338) .	„	8d. „
On the timbering „ . . .	„	6d. „
On the lighting, supposing that the production of one ton requires the work of one man for two shifts	„	3d. „
Total . . .		27d.

We may reckon that a cubic yard excavated furnishes ¾ ton of coal (1 metric ton per cubic metre), and we will suppose that it costs 7½d. to remove a cubic yard of overburden (1 franc per cubic metre). Theoretically, and *at a first glance*, when the thickness of the overburden is equal to the thickness of the coal multiplied by 2·7, it is a matter of indifference whether we adopt open or underground workings. (The saving per cubic yard of coal is $27\text{d.} \times \frac{3}{4} = 20\frac{1}{4}\text{d.}$, and the expense of uncovering 2·7 cubic yards of overburden is $2{\cdot}7 \times 7\frac{1}{2}\text{d.} = 20\frac{1}{4}\text{d.}$) This result agrees very well with practical experience; and consequently where a seam is very thick, we are justified in removing a very large amount of overburden.

We must furthermore add, that, in the above calculation, we have not taken into account the advantage of being able to work out the deposit more completely, and of being thoroughly free from danger of explosions.

Independently of the economic advantages mentioned, there is no doubt also that men work at the surface under more favourable conditions than underground. In the first place there is more light; and then an open quarry is healthier than a badly-ventilated mine, and safer than underground workings in loose ground.

The disadvantages of open workings are twofold. Firstly, there is the cost of removing the overburden; and secondly, the necessity of paying for the land destroyed in this way and required for piling up such rubbish from the overburden or the deposit, as

cannot be stowed away in abandoned parts of the workings. These disadvantages must be taken into account against the advantages enumerated above, and against the expenses which would have to be incurred in order to start underground mining.

Two points must not be forgotten in making this comparison. In the first place, if the open workings at the outcrop are some day to be followed by underground mining in the deeper parts of the deposit, the expenses alluded to are simply adjourned; in the second place, if the underground mining admits of the use of filling-up, the overburden may be employed as stowing, and so much of the cost of its removal may be charged to the mining account as would be incurred for procuring stuff from elsewhere. We can readily understand in this way how the limit of thickness of overburden, where open working would cease to be profitable, may be extended considerably.

It is thus very evident that the points which require looking into before starting open workings are of a very complex nature.

(358) Supposing that the question has been decided in the affirmative, the workings must be arranged according to certain very simple common-sense rules, which will vary somewhat according to local circumstances. The chief point is not to work at haphazard, but to lay out the workings by a well-matured plan, based upon a thorough knowledge of the characteristics of the deposit.

We must first determine the area over which we intend to work, and then fix on a point to begin with. The overburden should be removed over a considerable space so as to allow the use of large stopes—a characteristic feature of open workings—and so as to prevent any danger to the men from slips.

When once the actual work is begun, the mineral should be excavated as far as the floor, in the case of a horizontal bed, and, in other cases, down to the maximum depth proposed. This obviates the necessity of returning several times to the same place, and enables one to utilize the excavation as a receptacle for part at all events of the overburden from near at hand.

Efforts should be made to begin work, if possible, at the deepest

point, and always to work a little upwards. By this means the rest of the quarry is kept dry.

These general observations will be rendered plainer if we examine a few examples.

(359) As a first case let us take an alluvial deposit in the bottom of a valley in which there is running water. We must begin by turning off the brook on one side of the valley for the whole length of the "claim" or "sett."

The pit is started at the lowest point, and is carried up the valley for the whole width of the alluvium. The face is cut into stopes or benches so as to facilitate the breaking, and little roadways are made along the sides with gutters to carry off any springs which would furrow down the slopes. These roadways are connected by inclines for wheeling up the stuff in barrows. The back of the pit is formed by the natural slope of the rubbish that has been cast behind.

A shaft is kept up in the midst of the rubbish with a *fork* or *sump*, to receive all the water that runs out of the sides and what comes from the bottom of the pit. The water is carried to the *fork* by an arched drain, which is extended as the rubbish-heap advances, and it is raised to the surface by any suitable mechanical means. Figure 254 gives a plan and section of the arrangements just described.

(360) If the deposits occur as horizontal seams cropping out on the sides of hills, work is commenced at the outcrop itself, and the floor of the deposit is taken as the bottom of the pit. The rubbish is easily carried back and thrown down the side of the hill behind the workings (fig. 255).

The contour of the ground may be such as to prevent all the rubbish being disposed of in this way below the floor of the pit; as for instance, when the deposit crops out very little above the bottom of the valley, and when the overburden is very thick. *Horses* are then erected to carry a roadway over the workings, and the overburden is brought across this bridge and then tipped (fig. 256).

The first arrangement is employed, for instance, in the flagstone quarries near the tops of the hills, in the neighbourhood of Orsay, to the south of Paris; the second, in the gypsum quarries, to the north-west of Paris, at the foot of the hills at Argenteuil, Sannois, &c.

As the workings extend in further from the outcrop, the overburden increases in thickness. The rule that is followed to ensure the safety of the workmen in the stopes, is to cut the overburden to an angle equal to, or only slightly exceeding, that which it would assume after long continued weathering, and to preserve between the foot of the overburden and the first stope a distance equal to its own thickness. In the case of the beds of flagstone, which are 4 feet 3 inches to 5 feet ($1^m.30$ to $1^m.50$) thick, it pays to take off 40 to 50 feet (12 to 15 metres) of overburden, on account of the somewhat high value of the material.

With gypsum the thickness is relatively much less, and is often decided by the value of the land or buildings which would have to be purchased. When once this limit has been reached the gypsum is mined underground, in the manner described in No. **334**.

(361) When a bed has only a small dip, and crops out in a level country, it may be worked open for a certain distance from the outcrop: the rubbish and mineral are drawn up the sloping bottom of the pit.

In a case of this kind it will be found advantageous to combine open working with underground mining, because the *overburden* can be employed for *filling up;* besides which the mining shafts may be used for drawing up the mineral from the quarry, and also for draining it. This system, which was noticed at the end of paragraph **357**, enables one to carry on open workings to a much greater depth than would be otherwise economically possible.

The arrangements are shown in figure 257. A wide face is started from the outcrop and carried down, following the dip. Inclined galleries of varying length, driven along the floor of the seam, lead from the face to the underground workings on the dip

side. Part of the overburden is thrown into the back part of the quarry, and part is conveyed into the mine as it is required, by means of the inclines just alluded to. These same inclines serve to convey the mineral and water coming from the open quarry to the drawing and pumping shafts of the mine.

This system, which is rational and correct in principle, has been adopted on a large scale at the Commentry mines (Allier).

A large amount of carefully arranged plant has also been erected for quarrying parts of some thick seams of coal in the Coal Measures of the department of the Aveyron. We may call particular attention to La Vaysse mine, belonging to the Decazeville Company.

(362) When a bed or a mass cropping out in a plain dips at a high angle, the space occupied by the top of the quarry is relatively small, and the open workings can consequently be carried on deeper.

Such, for instance, is the case with the Angers quarries, which are worked on beds of slate, dipping away from the surface at an angle of 75° to 80° in a N.N.E. direction.

The valuable beds (*veins*) are intercalated in the midst of several thousands of yards of slaty rock; but the precise degree of cleavage or fissility, which renders the rock fit for making slate, is a matter of extreme delicacy, and experience shows that it is confined to certain narrow well-defined bands, so that new quarries cannot hope for success unless they are situated in the line of strike of those already at work.

The property in question does not exhibit itself thoroughly until a depth of 60 to 80 feet (20 to 25 metres) has been reached, where the slate is not exposed to the action of atmospheric agencies. Below this the cleavage remains perfect to the greatest depths hitherto explored, as much as 300 feet (80 to 100 metres) and more.

The first operation in opening one of these quarries is to clear away the soil and rotten ground near the surface. On reaching the solid rock a series of pits, 10 to 12 feet (3^m to $3^m.50$) deep, are sunk so as to form a rectangular excavation, which is deepened gradually.

The ends of the excavation at right angles to the strike are 60 to 70 yards (60 to 70 metres) apart, and are cut down almost vertically with a very few steps. These ends, according to their position, are called respectively the "eastern wall" (*chef du levant*) and the "western wall" (*chef du couchant*). On the firmer of the two walls, generally the eastern one, a scaffolding is erected to carry a pulley frame; a horse whim is put up behind it, or, better still, a drawing engine, raised a few feet from the ground by an embankment. The whole of the arrangement is shown in figure 258.

The box which is drawn up by the engine does not ascend vertically, but it follows a carrying rope, so that it may be dropped at any part of the pit. The object is to facilitate the removal of the large blocks, which are dressed at the surface, and to obviate the necessity of their being moved about on the floor of the quarry before being put into the box; this would be a matter of difficulty, and yet it would have to be done if the box always went to the same point.

The manner in which the problem has been solved at the Angers quarries is very ingenious and practical. There are two different arrangements—one with a carrying rope and leader, the other with a single rope. One end of the carrying rope is moored to any point in the bottom of the quarry, whilst the other is carried over a pulley on the scaffolding to a windlass, by means of which it can be tightened at pleasure. A pulley runs on this rope, and is connected with the leader by a chain (fig. 258 A).

The other arrangement (fig. 258 B) does away with the inconvenient fixed points in the bottom of the quarry. The rope is fastened on the wall opposite the winding engine, after passing over a pulley hung from a rope fixed parallel to the walls. In this manner the point of suspension may be varied, and at the same time the length can be altered by a windlass; the other end is joined to the drawing rope.

The box therefore always tends to place itself in a vertical plane passing through the two ropes, and it arrives at the point where the bottom of the quarry is intersected by an arc of a circle described in this vertical plane, the centre being the point of suspension, and the radius the length of the rope.

It may be interesting to note that these ingenious arrangements are precisely the same as those which are employed in some of the English slate quarries; the same wants in the two countries have led to the same inventions.

The south face of the quarry is made to follow the stratification, whilst the north side is cut into a series of upright stopes. The faces of these stopes are at first sloped off parallel to the dip, and on arriving at the northern limit of the sett they are cut vertically.

In order to deepen the quarry a long trench 3 feet 3 inches (1 metre) wide is cut from E. to W. by means of the pick and blasting; the trench is then widened right and left, and big blocks are got out 26 to 33 feet (8 to 10 metres) long, 11 feet ($3^m.30$) high, and 3 feet 3 inches (1 metre) thick. It is of much importance to procure the blocks as large and as little cracked as possible; in order to effect this object a vertical cut is hewn out with the pick at each end of the block for its entire height. This operation finished, the men endeavour to start a flat crack by blasting some small horizontal holes; and finally the block is slightly detached by firing a few holes bored in parallel to the cleavage. As soon as a crack has been made 15 or 20 wedges are gradually driven in by as many men, keeping time with their blows, for a period of several hours.

All that now remains is to turn over the block by means of levers, and then split it across and along the cleavage into blocks that can be handled by three or four men without too much trouble. In this state the blocks are raised to the surface and dressed into slates of the various sizes and thicknesses adopted in commerce.

The quarry is deepened gradually, and finally has to be stopped, either because the sides have become too weak from percolation of water or weathering, or else in consequence of the N. and S. walls converging and leaving too narrow a space to be worked profitably. Some of the slate quarries at Angers have been carried down 500 feet (150 metres) below the surface, a depth which probably exceeds anything that has been attained by workings of this kind in other localities.

We may here remark that the expense of removing the overburden may be obviated by working underground. The stopes may be arranged as in the open quarry, only they will be covered over by a flattish arch of rock rather thicker than the overburden. The N. and S. faces can be carried down with the dip of the slate vein, and when the north face begins to overhang too much, a strong pillar is left, and another story or floor started underneath it. In the same way a third may be started under the second, and so on.

We should therefore have, not an open quarry limited in depth, but underground workings which could be carried down indefinitely; in fact we should be working slate by descending floors or stories with solid arches of rock between them. With an arch of this kind, which may be 130 to 160 feet (40 to 50 metres) long by 80 feet (25 metres) wide, and may cover an excavation more than 300 feet (100 metres) deep, the workings assume an exceptional character. If the ground were to give way even slightly, very serious consequences might ensue, and therefore artificial bridges are made with the same curve as the natural arch, so as to enable it to be examined and any danger to be prevented in good time.

This system, which is a sort of transition between open quarrying, as usually practised at Angers, and true underground mining, which has to step in as soon as a certain depth is reached, is not perhaps everything that could be desired. Greater safety would be obtained—at the expense, however, of increased cost in getting the slate—by replacing this system of thick arches and enormous caverns by one of the ordinary systems of pillars and solid floors of rock. The solid floors would be thinner than the arches just alluded to, and would be sustained by pillars, or still better, by long continuous partitions parallel to the dip, and only occasionally broken through when it became necessary to have a communication. This, however, would no longer be a case of open workings, the subject we are dealing with at present.

(363) Open workings are also adopted for certain irregular deposits, such as the millstones of La Ferté-sous-Jouarre and

the oolitic iron ore of Central France found in *pockets*. These deposits occur at shallow depths, and are characterised by their *irregularity* or *discontinuity*. This want of continuity may be so great as to render it unadvisable to establish one central shaft connected with all the various workings. Such is certainly the case with the millstones, which are found in discontinuous beds underneath 10 to 12 feet (3 to 4 metres), or even 50 feet (15 metres) or more of sand and clay.

Before beginning any mining, the ground is probed with a pointed bar of iron, to ascertain whether or no a sufficient amount of stone exists in any given spot. The overburden is then removed, leaving a sloping face to prevent slips. At the same time a few ledges or benches are cut, with gutters to catch any water, which is raised from bench to bench up to the surface. An inclined plane is left on one side of the quarry, and the stone is brought up it on rollers either by levers or by a winch.

The stones are generally rough segments, which are finally dressed at the surface so as to form an entire circular millstone. The segments are cemented together by plaster of Paris, and bound around by hoops of iron. Good millstones made in segments are considered preferable to those cut out of one block, because the pieces can be arranged according to their quality, so as to have at every point the grain best fitted for the work required.

The millstones from La Ferté-sous-Jouarre (French burr-stones) fetch a high price by reason of their exceptionally good quality; and they are in great demand, not only in England, but also in America. They are rendered expensive by the cost of removing a great thickness of overburden, and of dressing the stone, an operation which requires a great deal of labour, and wears out many tools on account of the hardness of the material.

The deposits of oolitic iron ore differ essentially from the millstones, because they extend downwards to a considerable depth. Some of the open quarries have been worked to a depth of 160 feet (50 metres) when the masses have been large, as was the case at the celebrated Poisson quarry in the Haute-Marne. On account of the great development which has taken place in the metallurgical industries of France during the last thirty years

these open quarries have had to give place to underground mining, by means of which greater depths can be attained. The workings, however, have been carried on in a very limited manner. They have been very little extended laterally, and there has been great waste of mineral. At last, quite recently, people have recognized the advisability of working on a larger scale. Shafts have been sunk, and provided with winding and pumping engines, with a view to carrying on operations in lateral ramifications of the deposit as well as in depth; and it appears that the ore does continue down much further than the name of *pockets* or *potholes* (*mines en sacs*) would lead us to suppose. This term was erroneously applied to the deposits in question under the idea that they filled mere superficial cavities which were closed at the bottom, and had received their contents from above.

(364) In open workings, as a general rule, more or less deep cuttings are required, either in the overburden or the deposit itself. Very often the removal of the overburden constitutes the chief expense in working; it is therefore important to reduce to a minimum the expense of *uncovering a given area*, and this is effected by making the slope of the sides *as steep as possible*. Besides, this area must not be too limited, both for the reasons pointed out in No. 358, and because the proportion of rubbish due to the slope would be increased, and affect the net cost too much.

While we are thus led to increase the steepness of the slope in order to diminish the expense of the cutting, we must take care not to go beyond a certain point for fear of slips. These would seriously inconvenience the workings; they would endanger the lives of the men; and, when once started, they would be apt to extend very rapidly.

Attention must be paid, not only to the condition of the rocks when freshly cut, but also to the manner in which they resist weathering, a matter which must be taken into consideration if the quarry has to be kept open for some time.

Nothing but actual experience can teach us what is best to be done in any given case; however, a few remarks may be made on the subject.

(365) When we have to deal with stratified rocks lying horizontally, we may leave the sides perpendicular, provided all the beds are firm. The quantities crumbling away from weathering will be but small, and incapable of causing anything more than very slight and partial slips.

If, however, there are interstratified with the firm beds any others apt to scale off a good deal, these might weather away, and cause the overlying strata to hang over in a dangerous manner, especially if there were any joints parallel to the side. It is best to prevent occurrences of this kind by cutting away the soft rock for 2 or 3 feet ($0^{m}.60$ to 1 metre), and filling up the space with masonry.

Where the beds are inclined, the sides of the quarry are usually arranged so that two shall be at right angles, and two parallel to the strike. The two former sides may be cut down vertically, and so may the one side parallel to the strike where the beds are dipping away from the face. For extra security this face may also be cut at right angles to the bedding. Finally, the fourth side has to be varied according to circumstances.

If the different beds adhere to one another firmly, this side also may be cut perpendicularly; but if the dip is decided, or even if it is low and there are any wettish clayey beds likely to cause slips, it may be desirable, or even necessary, to cut away the fourth side along the stratification, so that no bed has its footing taken from it. This plan is also usually adopted when the dip is high.

What we have just said with regard to slips taking place along planes of bedding applies equally to clayey faults crossing the strata. In laying out a quarry the presence of these faults must not be overlooked, because they sometimes occur repeatedly, with a certain definite direction, and simulate a sort of stratification.

(366) If, instead of dealing with more or less firm rocks, we come to cuttings in soft or loose ground, such as clay or sand, or alluvial deposits generally, the sides must not be cut down perpendicularly; they have to be sloped off with inclinations varying with the nature of the ground, and, for a given material, varying according to the time that the excavation has to be kept open. If

a bank has to remain sufficiently long for the cohesion of the ground to be destroyed by weathering, we shall have merely to deal with the friction of the particles, and the banks will arrange themselves according to what is called the *natural slope of the ground*; that is to say, the inclination which the material would assume if it had been dug up and tipped over a spoil-bank.

This natural slope, or angle of repose, is comprised between inclinations with *a base of* 2 *and height of* 1 for the lightest sand, and with *a base of* 1 *and height of* 2 for strong clay. In each particular case we must keep within these limits, and the mean value of 1 to 1, or an angle of 45°, is often adopted. The natural slope of the ground that we have to work in may also be ascertained by direct experiments.

In any case, whether we are dealing with firm rocks or loose and soft ground, we must recollect that in the above rules for determining the proper slopes, the action of water upon the surface has not been taken into consideration. The rain which actually falls on the banks themselves has not, as a rule, any great effect, unless it acts on a very long slope, and on ground that is very easily washed away.

It is a very different matter if the upper edge of the cutting receives the drainage of a large area lying above it; for a great quantity of water running down the sides might furrow them so deeply as to render them unsafe, and at the same time partly fill up the bottom of the quarry with mud.

In a case of this kind, therefore, proper trenches must be dug in the ground above the cutting, so as to intercept the natural drainage and prevent the water from running into the pit; for, independently of the damage it might do to the sides, it would necessitate some pumping apparatus, unless the quarry were drained naturally.

(367) The examples we have given appear to us sufficient for making known the various arrangements applicable to the different cases which are likely to be met with in practice.

However, we have still to consider one special case which differs essentially from the preceding by the nature of the material worked and the conditions under which it generally occurs. It is worth

while examining the details of this case, both on account of the mode of working adopted, and because of the industrial importance of the substance in certain localities. We refer to peat, or turf, as it is frequently called.

Peat is a fuel of recent formation, indeed it is still being produced. It is derived from the more or less complete decomposition of plants, and principally aquatic plants, which have grown on the spot, under a small depth of stagnant or nearly stagnant water. These organic remains generally belong to species precisely identical, or very nearly so, with those living in the same places. This circumstance, as well as the actual situation of the deposits, indicates their recent origin; and they have evidently been formed since the last sculpturing of the surface by geological agencies.

Peat beds are formed in various ways; firstly, in secondary valleys with very little fall, such as those of the Essonne, the Juine, the Somme; or near the mouths of large rivers, such as the Loire; or in very low plains, as in Holland (*valley peat*). And, secondly, on more or less elevated plateaus with no very decided slope, on the watershed between two river basins (*plateau peat*).

The thickness of peat bogs, or turbaries, varies considerably, and may reach as much as 16 feet (5 metres) or more. In this case it is usually observed that the degree of alteration increases with the depth, and that the quality also improves at the same time. The first 3 feet, for instance, often consist of light, spongy peat, intermixed with vegetable fibres that are scarcely at all changed; this is called *mossy peat*. At the bottom of the peat bog, on the contrary, all traces of vegetable origin have disappeared, and we have a black, compact substance, known as *brown peat*. In going down through a peat bog we pass all the intermediate varieties.

As might be expected, we generally notice that the plateau peat is purer, and gives less ash than that of the valleys.

The formation of peat may be looked upon as an illustration of the manner in which the mineral fuels, and especially coal, have been formed, allowing of course for the difference in the luxuriance of the vegetation, the insufficient lapse of time since its growth, and the absence of metamorphic action.

From what has just been said we learn what localities are likely

to produce peat; and its presence is indicated by the perfect flatness of the ground, and occasionally also, when there is no thick covering of gravel, by the soil being shaky and springy. Of course its presence must be confirmed by the peat-cutter's borer (No. **104**). This instrument enables us to ascertain the extent of the peat bog, its thickness in various places, and the quality of its different beds, which are all matters requiring consideration before we should think of starting actual workings.

(368) The instrument which has long been in use for cutting peat is like an ordinary spade with a wing fixed at an angle of 100° to the blade. This spade [*slane, loy,* Ireland; *becket,* the Fen country; *turf-iron,* Dartmoor] (fig. 259) cuts therefore on two sides. The soil and any sand or gravel lying on the peat have to be removed, and then a first layer of peat, 1 foot ($0^m.30$) thick is taken off. A trench is first of all made, and then enlarged gradually by cutting a series of contiguous prisms [*sods, cesses, turves, peats*]; these only hold on by the base when they have been cut on two sides by the spade, and they are easily detached by a turn of the hand.

In former times a given area was worked over in this way for a thickness of 1 foot; then a second layer of the same thickness was cut, and so on till the water level was reached. When the peat-cutters wished to go down deeper, the water had to be drawn off; and as it soaked in from all parts of the porous mass around and under the pit, operations had to be confined to a very small area; for, otherwise, the work of keeping down the water would have been quite beyond the means at the disposal of the men. In fact the water was generally baled out with buckets.

This method allowed all the peat *above* the water level to be got, but *below* that level the pits had to be kept very small (3 yards square, for instance), and somewhat far apart, so as to prevent the workings from being impeded by an additional influx of water from the abandoned pits close at hand.

The consequence was that very much peat was lost, and a number of pits were left filled with stagnant water, spoiling the meadows altogether, and acting injuriously in a sanitary point of view.

(369) These two disadvantages have been entirely avoided by a very simple modification of the spade. By aid of the improved tool the whole of the peat may be worked *under water*, and the excavation may be made to extend over any desired area.

It would be difficult to find an instance where an industry has undergone a more complete transformation, owing to a simple modification of the tool, than has been the case in peat cutting, from the substitution of the *long spade* (in French, *grand louchet*) for the short one previously used.

The long spade (fig. 260) has two wings, and can take up 3 or 4 lengths of peat at once, say 3 or 4 feet ($0^m.90$ to $1^m.20$). The actual blade is not longer than that of the short spade, for fear of making it too heavy, but it carries a light sort of framework of thin sheet iron, and is fastened to a slender flexible handle 16 to 20 feet (5 to 6 metres) in length. Marks are made on it, 3 or 4 feet apart, according as 3 or 4 lengths are to be cut at once.

The mode of using the tool is founded on the fact that peat may be cut down perpendicularly for a considerable depth, especially under water, without slipping away. This is due to the tenacity of the peat, caused by the interlacing vegetable fibres of which it is composed. Care must be taken not to put too much weight on the edges of the cuttings, for otherwise the sides will bulge out and give way. This difficulty is met by making the man, who has to work at the edge of a cutting, stand on a plank, which serves not only to distribute his weight over a sufficient area, but also to guide the spade, as we will now explain.

Let us suppose that the peat has been dug away to the water level. The first operation consists in cutting a straight trench with the long spade (*grand louchet*) down to the bottom of the peat bog, and extending it for any desired distance. The trench may be made as narrow as is thought desirable, and the boring rod is used, if necessary, to determine the thickness of the peat.

When once a cut has been made in this way, a plank, 6 feet 6 inches (2 metres) long, is laid on the ground, and fixed in its place by two pegs 3 or 4 inches (8 to 10 centimetres) behind the edge of the cut. It serves, as we have just said, to carry the workman and guide his spade whilst he is cutting off a series of

contiguous prisms, and consequently the sides of their bases will be 3 or 4 inches (8 to 10 centimetres) wide. The spade is thrust down, and a first prism of 3 or 4 feet high is removed; it is then again thrust down in the same place, guided by the plank and the perpendicular face of peat, and a second lump is cut, and so on. The whole peat bog is thus removed in the form of a number of long, thin prisms, 3 or 4 inches (8 to 10 centimetres) on the side, equal in height to the total thickness of the bed, and divided into pieces 3 or 4 feet long. The peat bog is therefore finally replaced by an extensive *lake*, which is not specially injurious from a sanitary point of view.

It requires much strength and skill to use the long spade properly, and indeed the work can only be performed by picked men. However, the weight of the long piece of peat is not felt till the moment it is lifted out of the water. The workman has to incline the spade to prevent the peat from falling out of the iron framework. He lifts it out of the water in this position, and turns it over on the ground to empty it. The long prism is then cut into lumps 1 foot long, and these are put aside to be dried. Any pieces that are much mixed with earth are thrown back into the pit.

Such is the method now in use in the peat bogs near Paris and in the North of France. It has quite taken the place of the old method with its small isolated pits, and it may be looked upon as quite satisfactory.

The whole process comprises the following operations:

1. Removal of the vegetable soil, which may be utilized elsewhere.

2. Removal of the superficial gravel, which is made up into heaps and afterwards thrown back into the pit with any inferior peat.

3. Cutting the peat with the small spade over any given area to within a few inches of the water level.

4. Cutting out the *whole remaining thickness of the peat* with the long spade in the manner just described, making excavations of any size under water.

(370) In conclusion, we must say a few words about the manner in which the peat is dried. This can only be done in fine weather, and consequently in our northern latitudes the cutting should be carried on in the spring and concluded by the middle of May, and then by the end of September the peat may be stacked.

In order to dry peat thoroughly every lump (*sod, cess, peat, turf*), and every side of it in succession, must be exposed to the action of the wind and sun. The workman who receives the sods from the digger wheels them to the drying ground, and builds them up into little heaps. Each heap (in French, *rentelet*) is made of 15 turves, arranged in 5 superposed layers of 5, 4, 3, 2, and 1 pieces respectively. It is considered best to set up these heaps from north to south, so that they feel the full force of the prevailing winds. The space between two turves of the same row is made about equal to half their length.

The turves are often turned in various ways, and the position of the layers changed until they have become sufficiently hard on the surface. They are then built up into other heaps (in French, *cantelets*) consisting of 21 turves arranged in 6 layers, and finally they are built into the so-called *hedges* 2 to 3 feet ($0^{m}.65$ to 1 metre) high. These are little open-work walls built in herring-bone fashion, so that they may stand firmly in spite of their thinness.

In all these turnings and re-turnings care is taken to put the driest pieces at the bottom and the dampest at the top, so that every cess or turf may be equally dried by the action of the wind and sun.

It is necessary to keep the different heaps sufficiently far apart so that the air may circulate around them freely; the drying ground must therefore be pretty large. The ordinary rule is, that it should be equal to as many times the area of the peat cut in one season as there are feet of thickness of peat. Roughly speaking, then, there should be 3 acres of drying ground for every acre of peat 1 yard thick.

When the drying is concluded, and the autumn rains are approaching, the peat has to be stacked. The stacks (ricks or *reeks*) vary in size in different localities. They are made in the shape of truncated pyramids. The outside is carefully built up; but the

inside lumps are thrown in indiscriminately, and heaped up a little at the top.

If the peat has to be left out of doors during a part or the whole of the winter, the sides of the rick are covered with reeds to protect it from the weather, and the top is thatched. This covering will last for several seasons.

The cost price of a rick of peat of 18·3 cubic yards (14 cubic metres), and containing 9,900 turves obtained in the manner described, may be taken as follows:

		s.	d.		s.	d.
Digger . . .	2½ days at	5	0	per day . . .	12	6
Wheeler . .	4 ,,	2	6	,, . . .	10	0
Cutter, Stacker .	7 ,,	1	8	,, . . .	11	8
Thatcher . .	⅓ ,,	2	6	,, . . .	0	10
	Say 13⅝ days, costing			. . . £1	15	0

The peat would therefore cost about 1s. 10½d. per cubic yard (3 francs per cubic metre), or 3s. 6d. (4 fr. 25 c.) per thousand *cesses* on the ground, exclusive of the value of the land destroyed, which will form a more and more heavy item in proportion as the thickness of the bed diminishes.

This price is sufficiently low to make it worth while to employ peat instead of coal near the places where it is dug, not only for domestic purposes, but even for every kind of industrial use. But as peat is a cumbrous material, and as it is not ready for use till the bad weather is beginning to interfere with the cartage, it is never consumed in quantity at any great distance from the place of production. Thus, for instance, the manufactories situated in the upper part of the valley of the Essonne employ peat almost exclusively; those in the middle part employ peat and coal indifferently; whilst at Essonne itself, where the valley joins that of the Seine, peat can scarcely compete at all with the coal brought there by water.

In spite of the difficulty of securing a very extensive sale for their produce, peat-bogs are nevertheless properties of decided value for the immediate localities.

In France they sometimes belong to the parishes, and have to

be worked according to government regulations, under the superintendence of a Government Mining Engineer. He has to settle the mode of working, and the area that has to be dug up each year, and to bring forward all schemes for keeping up or repairing roads, canals, plantations, or other accessory works. The proposals of the engineer are not put into force until they have received the approval of the Prefect, and the money for carrying them out is usually raised by a small tax on the peat.

(371) The system described above is that which generally prevails in French peat-bogs.

It is a very satisfactory method, we repeat, *where it can be employed;* that is to say, when the top of the bed is at or above the water level. This, however, is not always the case. In some parts of France, but more particularly in Holland, the peat lies under water, which cannot be drained off. The depth of water above it varies a good deal, and the peat has to be got out by a dredge. Sometimes an ordinary scoop is used, like those employed for dredging sand from a river; but if the peat is sufficiently coherent, the scoop consists of a net fixed to an iron ring with a cutting edge at the end of a pole. The closeness of the mesh of the net depends on the consistency of the peat.

Peat which has been brought up by the dredge or net always requires to be moulded. In some cases a neighbouring meadow is mown very closely and covered with a little hay, and then the liquid peat is spread over it. It is kept in an enclosure by means of planks fixed by stakes. After it has been allowed to drain, it is *trodden on* by men who have boards fastened to their feet by leather straps. When the peat has been made sufficiently firm in this way it is divided into square prisms by two sets of cuts at right angles, and a little later these prisms are taken up and stacked in order that they may become thoroughly dry.

When the peat is not sufficiently liquid to run over the meadow it is shaped by hand in moulds resembling those used for making bricks. Sometimes the peat is moulded just as it is dredged up, or else it is first mixed with water, whilst any undecomposed fibres are picked out or raked out by hand.

Moulded peat (*hand-peat*, Ireland) obtained in this way is of better quality than ordinary peat, it is more uniform in texture, and possesses greater heating power; however, it is more expensive on account of the somewhat costly manipulation which it has undergone. Peat dug up with the long spade is also moulded in the same way when it is of a suitable quality.

The dredge should only be used where it is indispensable; that is to say, where the peat is actually under some depth of water which cannot be drained off. Otherwise we think that working with the long spade (*grand louchet*) is *probably* more economical, and certainly more favourable for removing the peat-bog completely and methodically.

We therefore look upon the long spade method as the normal system of working; and it is one which is capable of supplying either ordinary or moulded peat.

(372) This is the system which prevails almost exclusively in France. It is right to say, however, that the question of producing peat has frequently attracted the attention of inventors, and they have endeavoured to improve the methods of extracting it and preparing it for sale.

A large number of patents concerning peat have been taken out in France, and still more in England; for public attention has often been directed to the subject in the case of Ireland, where coal is scarce and peat-bogs are abundant. Details concerning some of these inventions, many of which are very ingenious, may be found in various journals, and especially in the *Bulletin de la Société d'Encouragement.* None, however, have passed beyond the trial stage and entered into the domain of practice.

It seems natural to us that it should be so, and in our opinion *no useful result* can be expected, at all events in France at the present time, from further researches in this direction. The deposits are too irregular, and individually too unimportant, the markets are too local and the property is usually too much divided, to make it worth while putting up permanent works and erecting machinery. This would necessarily be complicated, and would be expensive to buy and to keep up.

Besides, the small cost of getting peat by hand labour does not leave a sufficient margin for profit by machinery; and we may safely say that machinery, however perfect it may be, will always produce the peat at a higher price than the digger with his long spade, if we reckon in not only the cost of labour, but also the cost of keeping the machinery in order, and a sinking fund for redeeming the capital invested in it.

The attention of engineers who are interested in the progress of the art of mining should be directed to other matters, such as we have already pointed out and shall notice later on.

CHAPTER XIV.

UNDERGROUND HAULAGE.

(373) In this chapter we shall consider all the manipulations which the mineral undergoes from the moment it is broken down at the faces, until it is brought to the surface through a drift or level, or to the bottom of the winding shaft. The processes by which the mineral is broken down were described in chapter V., and the general arrangement of the working places in chapters XI. and XII.

The operations to be described here comprise:

1. Those of breaking, picking, and loading the mineral in the working places. They are easily described and understood, but they are nevertheless of the greatest importance, and require constant supervision.

2. An accessory haulage, which is often required, between the working place, or face, where the mineral is broken down, and the point where it reaches the *tub* or *tram-waggon* which traverses the underground railways. This intermediate operation should be done away with altogether, if practicable; or, if the conditions of the mine will not allow of this, it should at least be simplified as far as possible.

3. Lastly, the principal haulage on the underground railways, from the point where the tubs are filled to the point where they reach the surface or the bottom of the winding shaft.

The service of haulage grows in importance in proportion as the workings become more extensive, and as a larger output is required from the mines.

In accordance with the nature of the above details, this chapter may be conveniently divided into three sections.

§ 1st. Picking and loading in the working places.

(374) As we have already said, these manipulations may be *very well* or *very badly* done, however simple they may appear to be at first sight; and thus it arises that they have sometimes a decided influence on the success of a mining enterprise.

If, for instance, we consider the case of a series of stopes in a lode, we have seen in No. 275 what great and, so to say, *unlimited* loss of mineral can result, if the surface of the stowing on which it falls has not been properly levelled, and if the miners are not obliged to rehandle all the stuff broken down in order to sort it, and build up the deads in a regular manner behind them.

In the course of this rehandling all the pieces *necessarily* pass through the miners' hands. They have thus an opportunity to examine them, and may then sort them, *if they have an interest in doing so.* This last condition must not be lost sight of, because, as it is impossible for the agents to be constantly watching each working place, it is important that the mode of remuneration be so arranged that the miners have an actual interest in picking the ore properly.

It is therefore necessary either to adopt the system practised in certain English districts, notably in Cornwall, which consists in paying a company of workmen (*tributers*) a certain proportion of the value of the mineral obtained from these stopes after it has been properly dressed; or, if this system is rendered inapplicable by inexperience and want of enterprise on the part of the workmen, it is expedient to add to their pay, whatever may be the basis on which it is calculated, a certain premium proportional to the amount of mineral obtained.

This system may be rather delicate, and is always somewhat arbitrary when the amount of mineral is fixed without anything being settled as to its yield; for the workmen have then an inducement to increase the quantity by the addition of dead rock, or by not picking it out carefully enough. The disadvantage

of bringing a little more *deads* to the surface is, however, of less consequence than that of leaving useful mineral among the stowing; for all the expenses of getting this mineral have, so to say, been borne, and there only remains the cost of conveying it to the surface.

Thus we ought to be content when the miners have picked out enough dead stuff to fill up their excavations (*gunnisses*, Cornwall) completely, even if the ore is sent to the surface rather too much mixed with gangue.

In fact there is no great disadvantage if the picking underground is not thorough, so long as it may be completed at the surface in better light and with cheaper labour than that of the miners who work in the stopes.

It is more important *not to leave any useful mineral in the mien*, than *not to draw any dead stuff to the surface.*

There is, moreover, a certain middle course which should be pursued by the management in this as well as in many other cases. The workmen ought to submit themselves *in principle* to the supervision, which should *in reality* be exercised with firmness and constancy, and without any arbitrary alternations of laxness and excessive severity.

(375) In regard to coal, there are two elements to be considered; namely, *its cleanness and its largeness.* The merchantable value of the product depends greatly on these qualities.

For many years the small coal of whole mining districts was considered valueless, and was either left in the stowing below ground, or, in the fear of spontaneous combustion, it was brought to the surface, and burnt in heaps round about the mines. This time is now past, however, and we may rest assured that it will not again return.

Taking into account the facilities of transport of the present day, together with the many and various ways in which small coal can be utilized, such as for making coke, or by the adoption of special grates, or for gas generators, and lastly, for the manufacture of patent fuel, it may be said that *every kind of combustible material* has its value, and that that value will continue to increase rapidly.

Nevertheless, the difference between the value of the qualities will continue to exist, and might even increase, if not relatively, at least absolutely. There will, therefore, always be an important difference in price according to largeness.

The following varieties are distinguished commercially, in a descending order, both as regards largeness and price:

1. *Large* or *round coal*, properly so-called, consisting of *lumps*, or *blocks*, and not containing any pieces less than 7 to 8 inches cube (several cubic decimetres) in size.

2. *Nut-coal*, which consists of pieces measuring from at most 4 or 5 inches cube (1 to 2 cubic decimetres) to about the size of the fist.

3. *Through-and-through*, or mixed coal, which, as its name indicates, consists of the whole mass of the coal as it comes from the mine. Sometimes, however, in order to suit it to the usages or requirements of the trade, the lump-coal may have been picked out previously, or, on the contrary, it may have been freed from part of the dross by passing it over a *screen*.

4. *Small coal, dross, slack*, which consists of through-and-througn coal, without lumps or nuts.

The size of the through-and-through coal and the dross is often defined by stipulating that when passed over a screen, with bars at a certain width apart, usually ⅜ in. to 1⅛ in. (1 to 3 centimetres), they must not produce more than a certain fixed quantity of small passing through these bars.

A similar condition is often specified in regard to coal intended for naval purposes.

Large coal is bought for the navy, and it is stipulated that on its delivery the small arising from rehandling and transport shall not exceed a given limit. It is said, for instance, that the small obtained by passing it over a screen with the bars 1⅛ inch (3 centimetres) apart shall not exceed 25 per cent., and that if there is more than this the surplus will be left on the hands of the vendor.

5. Lastly, the small coal, properly so-called, or *duff*, is the coal which has passed through between bars of 1⅛ inch apart (3 centimetres) during the screening of any quality of coal whatever.

The prices of these various qualities decrease rapidly with the

size, and in certain cases the large coal may be worth twice as much as the small coal or more.

It is, therefore, of much consequence that the hewers should have an interest in keeping down the quantity of small to the lowest possible limit, and in producing the largest quantity of lump coal. For this purpose the mode of payment is so arranged that the sum paid for a given weight of large coal is very high relatively to that paid for the same weight of small; these payments form the entire wages of the hewers, or are at least an important addition to some other rate of payment based on the amount of space excavated, on the yard of advancement of the face, or on the extent of the surface from which coal has been removed.

As it is impossible to ascertain accurately the relative proportions of large and small coal in the working places themselves, or, indeed, in any place underground, it is necessary to bring the coal produced by any given gang of miners to the surface without mixing it with coal belonging to other gangs.

For this reason, as well as for others which will be mentioned further on, the system of bringing the tubs to the surface, marked in such a way that the working place from which they come can be easily recognized, is very much to be preferred to that of emptying them at the bottom of the shaft into large kibbles which receive the coal from all the faces indiscriminately.

If the place from which the tubs come is known on their arrival at the surface it is easy to weigh them, and to see after tipping them whether there is the proper proportion of large coal; the deductions which may be necessary are then made, and thus an accurate account is kept with each gang of workmen.

This easy control is certainly one of the great advantages which have been gained by substituting cages for kibbles in winding coal.

This substitution has been also advantageous with regard to both the cleanness and quality of the coal. The banksman is able to judge of these two particulars when he sees the tubs emptied.

He is thus in a position to make the proper reduction in the weight of a tub which contains too much dead stuff; or he may

reckon it all as small coal; or he may even omit to mark it down, *crop* it as it is called, if it is badly filled, or contains too much rubbish, etc., etc. In this case the supervision should be exercised with the same degree of moderation as in the workings of a lode. This system, from which the workmen naturally try to escape, can be carried on successfully by allowing no exemption from it, and by taking great care to choose only such overseers as will invariably give their awards with firmness and perfect impartiality.

(376) It will be seen that *as far as the largeness of the coal is concerned* the interests of the hewer are the same as those of the owners, because those methods of *getting* coal which are most conducive to the production of quantity are generally the same as those which furnish the greatest proportion of large coal. Thus it is that good hewers do not require to be urged to make their side-cuts and holings as deep as possible.

It is different, however, in regard to *the cleanness of the coal.* And here it may even be said that the interests of the hewer and those of the owners are opposed to each other; for the former will endeavour to obtain payment for dead stuff at the same rate as if it were useful mineral.

Perhaps it may also be said that it is the interest of the company, which has already paid for stones at the same rate as for coal, to send them to their customers, and that this interest increases with the selling price. Thus it is that the consumers are well aware that in proportion as coal becomes scarcer its quality deteriorates; and that, on the contrary, when it is plentiful and cheap, it is also *of better quality* and *more free from rubbish.*

We acknowledge that no mining firm with any self-respect would be guilty of such a practice; nevertheless, the effects pointed out will make themselves felt to a certain extent, because the workmen are more in demand in times of high prices, and consequently they become more exacting, more difficult to manage, and will not suffer such a close supervision as when labour is abundant and cheap. The actual result, therefore, is that in times of scarcity they send out a dirtier, and less carefully picked coal.

The measures that have to be adopted in the working place itself, in order to obtain a clean coal, are the following:

Firstly, to timber behind the face with a lining adapted to the nature of the roof, and in such a way as to prevent, not only the fall of large stones, but even the crumbling or partial fall of the beds, which possibly form a false roof. (See No. **181**.)

Secondly, to remove from the face, by means of a shovel, or even of a broom, all the earthy matters which have resulted from the holing, or from the fall of pieces of the roof or side, which may require to be taken down in forming the roadway.

Thirdly, to carry on the holing and side-cutting in such a way that the coal falls almost of its own accord, or at least with the aid of a very small quantity of gunpowder.

Fourthly, and lastly, if the seam is sufficiently thick, and has partings between the beds of coal, to profit by the presence of these partings in making the coal fall in successive stages, which have these partings either for a roof or floor, and so to simplify the process of cleaning; and in the same way, if the method of working is by under-hand stopes, to limit the various stopes to the lines of the partings.

These rules are not attended to everywhere as they ought to be, and in this respect there are great differences, according to the usages of the districts.

For instance, the miners of Belgium and the North of France, are much more careful as regards the cleanness of their coal than those of Central and Southern France. It may, perhaps, be imagined that this superiority of the former is not without its parallel in their domestic habits. Whether such be the case or not, this superiority is undoubted; and it may be said that, thanks to more constant attention, and greater cleanliness, seams can be worked in the neighbourhood of Liége, Mons, and elsewhere, which would certainly not be workable, at the present day, in Central and Southern France.

These results, however, cannot be attained without a most careful and constant supervision on the part of deputies, who are appointed for no other purpose than to constantly superintend the work of the hewers in a given district of the mine.

(377) Having been picked and sorted, as we have already said, the mineral is filled either directly into the tubs, or small waggons, in which it is conveyed to the surface, or into the boxes which are used for the purposes of an intermediate haulage between the working place and the points where the small waggons are stationed. In the former case the large lumps are usually lifted in by hand, and the small and medium-sized pieces by a shovel, after the two latter qualities have been separated by using a rake. A less clean and less effective method is to fill the medium-sized pieces with a pronged shovel, and the small which drops through with an ordinary shovel.

One man can fill in this way, in the course of a day, from 10 to 14 or even 16 tons (125 to 180 or even 200 hectolitres) of coal into small tram waggons of ordinary height; the differences in the quantities are due to variations in the height of the workings, and above all to the number of interruptions that may take place in the work. When the tram-waggons cannot be filled directly in the working place itself, the work of filling is connected with the accessory haulage in the manner which we are about to describe.

§ 2nd. Accessory haulage from the working place to the tram-waggon.

(378) At the present day all extensive mines are provided with a system of underground railways along their principal galleries. (It will be seen further on, by the aid of figures, that such a system is quite indispensable for the conveyance of many substances, such as coal; that is to say, with the large area which the workings now embrace, to give up the use of railways, and return to modes of conveying the mineral along the floor of the mine, would be equivalent to sacrificing the whole of the profits—either in consequence of the direct increase in the cost of haulage, or owing to the smaller output resulting from the crowding of the roadways, or lastly, on account of the generally increased cost price which would follow a reduction of the output.)

Although the employment of improved methods of haulage may, however, be necessary for the main galleries of a mine, the same

system may possibly be inexpedient, or even impracticable, for the service of each working place opened in any particular district.

We can at once cite a case in point of very common occurrence, and that is the working away part of a lode by a system of overhand stopes, as described in No. **270**.

The same case is met with in the workings of a highly inclined coal seam. (No. **293**.)

Even in a mine, however, in which all the working places are at the same level, the thinness or irregularity of the seam, or the instability of the floor, or its unevenness, or the presence of faults throwing down small areas of coal, &c., &c., render it inexpedient to incur the cost of extending the railways to all the working places. It then becomes necessary to institute certain modes of conveyance between the working places and the railways.

In a steep working, arranged in the form of overhand stopes, the mineral is filled into wicker baskets provided with two handles, and these are carried either in the hand, or on the head, to the top of the *pass, shoot,* or *mill,* into which their contents are emptied. The pass is kept nearly full, to prevent the pieces from falling too far, and becoming broken up. At the lower end it terminates in a trap-door, which is opened in order to fill the small waggons as they are run under it.

It is not finally emptied until it has served to discharge the stuff from the highest stope. It then remains empty, or, if necessary, it is filled up with dead stuff which happens to be produced in too great quantity elsewhere.

The passes should be arranged in such a way that the stuff thrown into them shall be unlikely to choke them. This object cannot always be attained, however, especially when they are not vertical.

When such an accident does occur it becomes necessary to clear them out, and this operation requires experienced and able workmen. One of the measures that should be taken to render the occurrence of these accidents less likely, is to construct the passes tapering upwards slightly, and to line them with wooden planks.

(379) When it is necessary, not merely to climb up or down the

height of one or two stopes in order to reach the mouth of a pass into which the baskets can be emptied, but also to traverse a considerable distance along the floor of the levels, the baskets may be carried on the back, or drawn along the floor, or, lastly, some kind of rolling apparatus may be employed, such as an ordinary wheelbarrow, or a small cart on several wheels. If the distances are short, men are employed at this work; and if they are long, and the extent and importance of the district justify such a step, horses are used.

From the nature of the observations made in No. **39** of the *Cours des Machines* it is evident that no kind of theoretical estimate, not even an approximate one, can be given of the amount of work which men can accomplish in the circumstances described above. We can merely make a few observations of a general character, and bring forward certain numerical data which have been deduced from the study of particular cases.

(380) Carrying on the back is performed by the miners themselves, or preferably by young persons paid by them.

The load which a workman can carry is comprised between the extreme limits of from 90 to 150 pounds (40 to 70 kilog.). It is very generally from 100 to 135 pounds (50 to 60 kilog.). It varies not only according to the age of the young persons, as might naturally be expected, but also with the conditions of the locality in which the work has to be done, especially with the height of the roadway, and its state as to temperature and ventilation.

The condition of the floor of the roadway is not of much consequence, so long as the carriers have good lamps.

Mixed coal is carried in bags on the back of the workman, who steadies them with his left hand, and holds his lamp and a short walking-stick, on which he leans, in the right hand.

The large pieces are borne on the back on the top of the sack, which is folded over the load.

The distance through which a load of this kind is carried in one day varies from 4,300 to 6,500 yards (4,000 to 6,000 metres).

The useful effect is therefore comprised between the limits given by the figures $90 \times 4{,}300 = 387{,}000$ $(40 \times 4{,}000 = 160{,}000)$, and

$150 \times 6{,}500 = 975{,}000$ ($70 \times 6{,}000 = 420{,}000$), the mean being perhaps about $110 \times 5{,}465 = 601{,}150$ ($50 \times 5{,}000 = 250{,}000$).

These three numbers—387,000, 975,000, and 601,150 (160,000, 420,000, and 250,000)—do not represent yard-pounds (kilogram-metres) in the sense usually attached to that term in mechanics; for the question is not of a load raised vertically, but of one moved horizontally.

The mean number 601,150 (250,000) is equivalent to the transport of one ton through a horizontal distance of 268 yards (one metric ton 250 metres), or 2⅔ tons over a distance of 100 yards (2½ metric tons 100 metres). Supposing, then, that the carrier receives 2s. (2 francs 50 cents) per day as wages, the cost of carriage will amount to 9d. per ton per 100 yards (1 franc per metric ton per 100 metres), or 13s. 2d. per ton per mile (10 francs per metric ton per kilometre).

The last figure makes it very evident that it would be *quite impossible* to resort to carrying on the back as a means of underground transport for greater distances than a few hundred yards. In a coal mine, for instance, the extra cost which would result for carriage per ton of coal would much exceed the profits derived by the sale of that weight of coal.

If this means of carriage is more expensive than any other, however, it is, on the other hand, the one which requires least preparation of the roadways on which the men have to travel; it can adapt itself to the most exceptional circumstances; for men can pass anywhere, either on the natural floor of the seam, or on steps cut in the floor, or on nearly vertical ladders.

One of the conditions necessary in order that the distance travelled per day may lie somewhere between the limits of 4,300 and 6,500 yards (4,000 and 6,000 metres) is that the vertical height which has to be traversed is only a small fraction of the whole distance.

If we wished to ascertain the distance that could be travelled vertically in this manner, that is to say, considering the operation as a means of raising mineral vertically, rather than as a method of horizontal transport, we should find that the useful effect was comprised between the numbers 361,650 and 433,980 (50,000 and

60,000), and these numbers would in this case actually represent *foot-pounds* (*kilogram-metres*) in the proper sense of the word.

(381) Carriage of mineral by means of sledges drawn along the floor is more economical than carrying on the back, because the muscular effort to be sustained by the workmen no longer consists in supporting the weight of the load. The weight which can be transported in this manner is not limited *à priori*, or *per se*, but is dependent on the coefficient of friction between the floor of the gallery and the vessel in which the load is carried.

Any weight might therefore be transported in this manner, but the amount will, of course, vary with the condition of the roadway; for this mode of conveyance is not superior to carriage on the back, unless the gradients of the roadways are comparatively regular and the ups and downs slight.

It is thus necessary that the floor of the gallery should be almost uniform, or at least free from sudden inequalities, such as would be produced if stones from the roof were allowed to remain on the floor.

Hauling up slopes becomes very difficult when the gradient reaches or exceeds ten degrees; and where there is a slope of this kind for a distance of twenty or thirty yards, for instance, it becomes necessary to station a *putter* at the bottom of it to assist the successive *hauliers* in passing over this part of the roadway.

A slope of twenty degrees is about the highest gradient which can be traversed in this manner.

When the inclination is as much as fifteen degrees the sledge will descend of its own accord, and in ascending a slope of this kind the workman finds it better to carry the empty sledge on his back than to drag it along the floor.

When the slope is greater than fifteen degrees the sledge requires to be held back during its descent. This can be done in two ways: the workman either places himself in front, and leans his back against the front end of the sledge, and thus allows himself to be pushed along; or else he places himself behind the sledge, and holds it back by means of a *rudder* (fig. 261), consisting of two hooks at the end of a pole, which grasp the edge of the tub. The sledge is

then allowed to descend in front, while at the same time it can be turned by the handle of the rudder, and thus made to follow the windings of the gallery along which it happens to be passing. With this arrangement the haulage may be carried on with slopes amounting to twenty-five or thirty degrees.

These two limits, fifteen or twenty degrees for ascents and twenty-five or thirty degrees for descents, may be even exceeded when a fixed pulley is placed at the upper end of the slope provided with a chain of the same length as the steep part of the roadway; of course, when one end is at the top of the incline, the other must be at the bottom.

When a sledge has to be let down, it is fastened to the chain at the upper end, and the chain in being drawn up acts as a break.

If, on the other hand, a sledge has to be drawn up, it is fastened to the lower end of the chain, and the haulier ascends to the top of the incline alone; he then takes hold of the free end of the chain, and pulling it downwards causes the sledge to ascend. After the sledge has reached the top, he again walks up the incline and continues his journey.

It is often possible, moreover, to establish a *meeting-place* at these points. Each haulier then fastens his sledge to his end of the chain, and as he follows it he holds it back, or pushes it, according to circumstances. They of course arrive at the opposite extremities of the incline simultaneously; they then detach their sledges, and each pursues his own course.

Such is the very simple manner in which this system of haulage is organised.

The vehicles with which it is accomplished consist either of mine-baskets or small elliptical tubs, which are sometimes fixed permanently on runners, sometimes placed on small sledges provided with these runners. A tub of this kind may, for example, be 2 ft. 3½ in. long, 1 ft. 6 in. wide and 2 ft. deep ($0^{m}{\cdot}70$, $0^{m}{\cdot}45$, and $0^{m}{\cdot}60$); its weight will be about 66 pounds (30 kilog.), one-third for the wood, and two-thirds for the ironwork, and its price, 12s. to 16s. (15 to 20 francs).

A sledge-tub for horses, capable of carrying 5 to 6 cwt. (250 to

300 kilog.), weighs about 2½ cwt. (130 kilog.), and costs about £3 4s. (80 francs). (For the details, see figure 262, which represents a sledge-tub of this kind of the type formerly employed at St. Etienne, both for haulage and raising the mineral in the shafts.)

The sledge-tubs are drawn by means of a short iron chain, which is hooked into a ring or loop, fixed near their bottom, or on one of their cross-pieces. At the other end of this chain there are straps, which the haulier places across his breast. The pull is therefore off the ground, and consequently favourable to the haulage when deep ruts or other obstacles are met with on the way.

This kind of haulage is sometimes carried on by horses instead of men.

The tubs are then larger, and are often drawn two abreast. One end of a piece of chain is fastened to the traces of the horse, and the other to two chains hooked on to the tubs.

The useful effect obtainable by this system of haulage may be calculated by means of the following elements:

For young persons travelling in high galleries, the tub contains 4 bushels (1⅛ hectolitre), or about 2⅜ cwt. (120 kil.), and the distance traversed with the loaded tub is 3¾ miles (6 kilometres). (With well-made roads and long journeys as much as 5 miles (8 kilometres) has been reached.)

For children travelling in low and difficult galleries, the load is reduced to 1¼ cwt. (60 kilos.), and the distance traversed with the full tub to 2¼ miles (3,500 metres).

Lastly, horses may be employed instead of either men or children. Theoretically, and in a general way, it may be said that the motive power of horses is more economical than that of men; but horses are more susceptible to the influence of a high temperature and bad ventilation, as well as to the state of repair of the galleries in which they are at work.

As a consequence, it has been remarked that the load varies, according as these circumstances are more or less favourable, from 4 to 12 and even 13¾ cwt. (200, 600, and 700 kilogrammes).

The distance travelled with the load is about 3 miles (5,000 metres), and this has a tendency to increase as the length of each journey is greater, or, what is the same thing, as the number of

separate journeys is less, and consequently less time is lost at each end.

It may be assumed that the mean load for horses will be two double-sided tubs of $4\frac{3}{4}$ cwt., or in all $9\frac{1}{2}$ cwt. (480 kilogrammes).

To recapitulate, then, we have :—

For young persons employed as hauliers in ordinary galleries a useful effect indicated by the number $2\frac{1}{2} \times 3\frac{3}{4} = 9\frac{3}{8}$ ($120 \times 6{,}000 = 720{,}000$).

For children in low galleries the number $1\frac{1}{5} \times 2\frac{1}{4} = 2\frac{7}{10}$ ($60 \times 3{,}500 = 210{,}000$):

For horses, $9\frac{1}{2} \times 3 = 28\frac{1}{2}$ ($480 \times 5{,}000 = 2{,}400{,}000$).

Supposing that the young men are paid at the rate of 2s. 6d. (3 francs), the children at 1s. 8d. (2 francs), and that a horse costs 5s. (including redemption of first cost, and the wages of the driver) per day, we find that the cost of haulage per ton per mile amounts in round numbers to 6s., 12s. 4d., and 3s. 6d. (4 fr. 15, 9 fr. 50, and 2 fr. 50 per metric ton per kilometre).

These figures are all lower than the cost of carrying on the back, and at the same time they show the immense advantage of giving sufficient height to the galleries, and substituting horses for manual labour. It is also evident that these advantages cannot be obtained unless two conditions are fulfilled. *On the one hand*, the quantity of mineral carried through a gallery must be sufficient to make the economy resulting from the employment of this system of haulage pay for the expense of raising its height; and, *on the other hand*, the amount of haulage required in a given locality must be sufficiently great to keep each horse actively employed.

This observation must not be overlooked; and a similar examination should always be made in deciding whether it is advisable to lay out money for effecting a certain economy in any kind of commercial undertaking. It is always necessary to ascertain whether the scale on which the economical result will be obtained is sufficient to reinburse one for the proposed outlay.

In the present case we must suppose the distances to be great enough, the roadways in sufficiently good order, the temperature and the ventilation to be favourable, and the quantities of stuff

requiring to be transported sufficiently great. If these conditions were fulfilled, horses might be employed to full advantage, and a great economy would result from their use. Large horses are used in galleries of ordinary dimensions, and small horses or ponies, certain kinds of which are not more than 9 hands ($0^{m}\cdot90$) high, can be adopted in low roadways.

When the workings communicate with the surface through a level, or incline with a moderate dip, the stable is situated at the surface, and the horses are brought out of the mine every day; otherwise they remain constantly in the mine, and the stable should then be placed near the intake airway, and not far from the downcast shaft. They are lowered into the mine by means of the winding rope, somewhat in the same way as cavalry horses are embarked on board ships. In the first place their eyes are bound, and then they are enveloped in a kind of net; a strap provided with a ring is next fastened to each foot, and a cord having been passed through the rings is drawn suddenly tight, so that the horse falls down on a bed of straw placed in readiness for it.

After this the engine rope is attached to the upper part of the net; the horse is thus lifted, and then lowered into the mine in a sitting posture, resting on his haunches. A man is sometimes placed above him with a lamp so as to guide him during the descent.

At the present day, where the winding compartments are of sufficient dimensions, the horse may be taken down in his natural posture in a kind of stall or box provided with two doors, one at each end, opening outwards. One door is opened to allow the horse to enter the box, and the other after he has reached the bottom of the shaft to allow him to walk out. He thus enters and goes out on his own feet without any difficulty.

Instead of a special box of the kind just described, it is often possible to employ the cages themselves in pits provided with guides.

(382) For conveyance along the floor of the mine, carriages with wheels may be substituted for sledges. These may be either common barrows wheeled by men, or trucks, tipcarts, or tumbrils drawn by horses.

The wheelbarrow, which is said to have been invented by Pascal, is well suited for utilizing manual labour when it is properly made. Indeed, if the shafts are made long enough, and the body be widened sufficiently at the top, and placed so that most of the weight is borne by the axle of the wheel (fig. 263), the effort required to lift the wheelbarrow can be greatly diminished, or, in other words, the greater part of the weight of the barrow and of the load is carried by the wheel, and not by the arms of the workman. The workman has thus, as it were, only to push horizontally. Compared with sledging, the strain is *extremely small*, for the work to be done in both cases should be equal to the friction which has to be overcome by the vehicle. In the case of the sledge, this friction was on the floor; whereas in that of the barrow, it is that of the nave of the wheel on the axle. The work against friction is diminished, however, both because the coefficient of friction is less and the distance traversed by the rubbing surfaces is reduced in the proportion of the diameter of the wheel to that of the axle.

The same considerations apply to a two-wheeled cart; and if it has four wheels, the load is carried entirely by the axles, and the horse does not require to support any part of it.

The wheelbarrow is not always as well made as it should be; the body, more especially, is often badly shaped and badly placed, so that the load has to be reduced because it does not lie sufficiently over the axle. As a consequence, barrows of this kind cannot carry more than 132 or 154 pounds (60 or 70 kilog.) instead of 200 or 220 pounds (90 or 100 kilog.), as they should do if properly made.

The men usually work in relays; they traverse a given distance in one direction with a full barrow, and bring back an empty one on returning. The barrows run either on the floor itself, or on a line of planks laid along the floor. The stages are 30 yards on a level, and 20 yards on an incline of 1 in 12—the gradient which is adopted when it becomes necessary not only to transport the stuff horizontally, but to raise it a certain height; for example, in order to rise out of a shallow cutting.

Under these conditions the men make 450 journeys per day.

Assuming the load to be the minimum one, 132 pounds (60

kilog.), the useful effect is thus $132 \times 30 \times 450 = 1{,}782{,}100$ ($60 \times 30 \times 450 = 810{,}000$), and the distance traversed with a load is $30 \times 450 = 13{,}500$ yards ($30 \times 450 = 13{,}500$ metres). The whole distance passed over is, therefore, 15 miles (27 kilometres), which is evidently too much, since a walk of that extent alone is already fatiguing of itself. It is, therefore, better to reduce the speed of the wheelers and increase the amount of the load.

With a wheelbarrow of the form and dimensions shown in figure 263, the load may be increased to at least 220 pounds (100 kilogrammes), and the distance to be traversed with the load reduced to 11,000 yards (10 kilometres). The useful effect is then measured by the number $220 \times 11{,}000 = 2{,}420{,}000$ ($100 \times 10{,}000 = 1{,}000{,}000$), which makes the cost of carriage 4s. per ton per mile (3 francs per metric ton per kilometre), if we reckon the wages of a man at 2s. 6d. (3 francs) per day.

With an ordinary cart, or a tumbril, drawn by one horse, the load may amount to 1,540, or 2,200 pounds (700 or 1,000 kilog.), if the roadway is in good condition, and the distance traversed with the load, to 13,120 yards (12,000 metres), if the stages of the journey are so long that their number is relatively small; the useful effect is then $2{,}200 \times 13{,}120 = 28{,}864{,}000$ ($1{,}000 \times 12{,}000 = 12{,}000{,}000$), at a cost of 5s. (6 francs) per day, or 8d. per ton per mile (50 centimes per metric ton per kilometre).

This result is *very favourable* compared with that obtained with wheelers; but it is exceedingly rare that this mode of transport can be resorted to on account of the ordinary dimensions of the galleries, which are not adapted to it, and the difficulty there would be in keeping them in good repair, and in a good state for haulage.

When the conditions are favourable to the employment of a cart much advantage would be gained, as will be seen further on, by resorting to the use of railways, which give a much greater useful effect with horse-labour. Besides, when the railway has once been made, the cost of keeping it in repair is not of much account.

(383) If we except the use of carts, the cost of the other means of conveyance actually applicable in most mines to the short or

medium distances which have to be traversed, in order to reach the main railways, varies from 13s. 2d. per ton per mile (10 francs per kilometre), the cost of carrying on the back, to 4s. per ton per mile (3 francs), the cost of conveyance by barrows, and 3s. 6d. per ton per mile (2 fr. 50) the cost of sledging with horses.

These figures are *excessive* when considered in connection with the extent of modern workings, which has a tendency to increase in proportion as the mines become deeper, and require more heavy machinery.

The means of haulage hitherto described cannot be employed except for short distances, or for the purpose of conveying the products of several working places, forming a limited district, to given points on the main railways.

As far as the haulage throughout the whole extent of a large mine is concerned they can be set down as *totally inadequate*, and it may be asserted positively that railways are an indispensable kind of plant in such a mine.

Moreover, there does not appear to be any valid reason why they should not be employed.

§ 3rd. Haulage on Railways.

(384) The miniature railways underground are usually constructed with a great degree of simplicity. They may consist of simple bars of iron placed in grooves cut in wooden cross-pieces (*sleepers*), and held in position in these grooves by means of wedges (*keys*).

The wedges are made so that they are not likely to get out of the grooves in which they are also jammed; they are often placed on the inside face of the rail, so as to reduce as much as possible the total length of the sleeper required for a given width of rails. (See fig. 264.)

The gauge of these railways is limited for the most part by the width of the galleries, and it is usually found to be of great importance to make the galleries as narrow as possible, for the sake of reducing the cost of keeping them in repair. The usual width between the rails varies from a maximum of 2 feet 7½ inches

($0^m.80$) to a minimum of 19¾ inches, or even 17¾ inches ($0^m.50$ and $0^m.45$). The section of the rail, or the weight per running yard, *necessarily* varies with the weight of the carriage employed, and also *to a certain extent* with the gauge, inasmuch as the lightest waggons are generally used on the narrowest tracks.

The following figures may be accepted as approximate, with the remark that if any alteration is made, it is wiser to *exceed* than to *fall below* the dimensions given, since breadth of rail is favourable to the preservation of the wheels, and weight and depth give solidity to the track. The rails are supposed to be fixed to transverse sleepers 2 ft. 2 in. ($0^m.67$) apart, and their weight should increase or diminish according as the gauge is greater or less than the above amount.

Weight of the Loaded Waggon.		Height of the Rail.	Width of the Rail.	Weight per Running Yard.	(Wt. per Running Metre.)
6 cwt.	(300 k.)	1⅝ in. (40^{mm})	⅜ in. (10^{mm})	6·26 lbs.	(3·71 k.)
10 cwt.	(500 k.)	2 in. (50^{mm})	⅜ in. (10^{mm})	7·83 lbs.	(3·89 k.)
14 cwt.	(700 k.)	2⅛ in. (55^{mm})	½ in. (12^{mm})	9·22 lbs.	(4·67 k.)
18 cwt.	(900 k.)	2⅙ in. (60^{mm})	⅗ in. (15^{mm})	14·11 lbs.	(7·00 k.)
24 cwt.	(1200 k.)	2¾ in. (70^{mm})	⅗ in. (15^{mm})	15·76 lbs.	(7·82 k.)
30 cwt.	(1500 k.)	2¾ in. (70^{mm})	11/16 in. (18^{mm})	20·68 lbs.	(9·81 k.)

Taking into account the fact that the price of iron is very variable, having risen, for example, during the two last years, to a height from which it is again likely to decline in consequence of the setting in of a reaction, we may make the following rough estimates of the cost-price of two railways intended for waggons of different weights. One is suitable for waggons of 24 cwt. (1,200 kilog.) which exceeds the ordinary limits, and the other for waggons of 10 cwt. (500 kilog.) which is a very usual weight.

1st. Price per running yard (metre) of a railway suitable for the waggons of 24 cwt. (1,200 kilog.)

	s.	d.	francs.
Rails, 32 lbs. (16 k.) in round numbers, at 9s. per cwt. (22 fr. per 100 kilos.) . . .	2	8	(3.52)
One and a half Sleeper, at 1s. (1.20 fr.) each .	1	6	(1.80)
Three Notches, at ½d. (0.05 fr.) each . .	0	1½	(0.15)
Three Wedges	0	0½	(0.05)
Cost of Laying	0	2½	(0.25)
Clearing bottom of level and ballasting . .	0	4½	(0.5)
Total per yard (metre) . .	4	11	(6.27)

As regards this price, it should be said that if the railway be removed after it has been in use for some time, the rails will have almost the same value as at first, and about two-thirds of the sleepers will be of use; we have thus recovered 3s. 8d. (4 fr. 70.) On the other hand, it is necessary to take into account the expense of lifting the rails, and in this way we find that the cost of putting down a temporary railway in a gallery is 1s. 6d. per yard (2 frs. per metre) almost, in round numbers.

2nd. Cost per running yard (metre) of a railway for a waggon containing 10 cwt. (500 kilog.)

	s.	*d.*	francs.
Rails, 17 lbs. (8 k.), at 9s. per cwt. (22 fr. per 100 kilos.)	1	4	(1.76)
One and a half Sleeper, at 9d. (0.9 fr.) . .	1	1½	(1.35)
Three Notches, at ½d. (0.05 fr.) each . .	0	1½	(0.15)
Three Wedges	0	0½	(0.05)
Cost of Laying	0	2	(0.20)
Clearing bottom of level and ballasting . .	0	3	(0.30)
	3	0½	(3.81)

Reasoning in the same way as in the preceding case, we find that the actual expense of laying down such a railway temporarily in a gallery does not exceed 1s. 3d. per yard (1 fr. 50 per metre).

(385) A railway constructed with simple flat bars is usually sufficient for the wants of an ordinary amount of traffic underground.

Nevertheless several other variations which have been proposed or adopted should be mentioned; the commonest of these is to make use of stronger rails of Vignoles' section. Railways of this kind are usually laid down in the principal galleries, where they have to last for a considerable time, and undergo a good deal of wear and tear on account of an active traffic, especially where the haulage is carried on by means of fixed engines and wire ropes. These rails are fixed with spikes in the same way as those of railways at the surface.

Another arrangement is to have a single rail fastened to the timber at a certain height above the floor of the gallery. The

mineral is then carried in a box suspended to the block of a grooved pulley which runs on the rail.

We mention this arrangement, which was employed in certain mines in the district of the Loire, in which the floor *crept* so much that it was not thought possible to lay an ordinary line of rails on it. Although the railway placed in this position escaped the direct effect of the movements of the floor, it was nevertheless affected by them indirectly through the breaking and bending of the timber to which it was fastened. Moreover, the want of stability and the swinging about of the boxes, together with the high cost per running metre for making the railway, soon led to the abandonment of this method. We only mention this arrangement historically, as it were, and for the purpose of showing what was done at one time in order to escape from the difficulties, more imaginary than real, which seemed to be inimical to the employment of railways in certain mines, and actually retarded their adoption for a long time.

Various methods have also been proposed for constructing the railways entirely of iron. In some cases the sleepers are of flat iron, and have chairs cast on them, which serve to fix the rails in the same way as on an ordinary railway. In other cases the sleepers are hollow and longitudinal, and have a rib along the top, which is capped with a bridge, or Brunel rail. Longitudinal sleepers must be properly tied together.

Hitherto, however, none of these arrangements have been adopted extensively; but they may possibly come more into use in the future as the price of wooden sleepers rises.

We may also mention railways with hollow rails or tramways; others with bands of iron placed on flat longitudinal sleepers; with wooden rails, &c.

None of these arrangements, which have much exercised the wits of inventors, are as good as bars of iron placed edgewise, or the small Vignoles' rails. The rolling resistance on them is always greater, because they cannot be kept so thoroughly clean; and this is a matter of extra difficulty in a mine.

Our opinion is that, for the present, small bars placed edgewise in transverse wooden sleepers are best for the less-important

railways, and small rails of ordinary section for the principal galleries in which there is much traffic.

(386) Without referring at present to gradients or curves, which will be treated further on, when we come to speak of the rolling stock, we ought here to distinguish junctions and crossings as peculiar points requiring special arrangements.

A junction, such as that shown in figure 265, has three points—A, B, and C—which have to be examined. We shall suppose the railway to be one of ordinary construction, that is to say, with edge rails, and that the wheels which run on them have a rim or flange on one side inside the rails.

The question which has to be solved is the following: It is necessary that waggons coming from the direction X on the main line of rails, or from the direction Y on the branch, should be able to continue their course towards Z on the main line, of their own accord; and, inversely, that waggons coming from the direction Z can be made to follow the line ZX, or to run into the branch in the sense ZY *at pleasure.*

There is a crossing at C which should be so made that the flange of the wheel which runs on the inside of each of the rails meeting at that point should not be obstructed by the other rail. Both of the rails must therefore be cut so as to allow the free passage of the flange, both in width and depth. This is effected by making a horizontal cut in the ends of each rail on a level with the top of the sleepers, and bending the upper part outwards, as shown in figure 266. This arrangement allows of the rails being fixed in the sleeper with wedges in the ordinary manner. The two other ends are cut at a slant and welded together, or they are left square, and abut against a triangular piece of cast iron, which is bolted to the sleeper.

At the points A and B, the exterior rails are continuous, that is to say, at A the rail of the main line, and at B that of the branch, while each of the others has a switch which can turn round on its extremity *a* or *b*, and thus be brought close to, or removed away from, the corresponding rail A or B, according as it is wished to establish the continuity of one line of rails or the other. (See figure

267, which shows the points A, B, *a*, *b*, of figure 265 on a larger scale, and with more details.)

When it is desired to run from Z towards X, the switch *a* A should be open, and the switch *b* B closed, and inversely when it is desired to enter the branch going from Z towards Y. Lastly, in running from X or Y towards the main line Z it is not necessary to touch the switches, as the flange of the wheel itself forces them into the proper position, even if they have not been so situated beforehand.

Sometimes the switches are left out, and the parts *a* A and *b* B are fixed; there is merely a groove left at A and B deep enough and wide enough for the flange of the wheel to pass through. With this arrangement, which is shown in figure 268, there is no difficulty in running on the main line; but on coming in the opposite direction, instead of having to open the switches in order to follow one road or the other, an operation which always takes up a little time and care, it is only necessary to push the waggons in the sense required to make the flanges of the wheels run upon the road it is desired to follow.

Thus, for example, if we take figure 268, it would be necessary to push the waggon towards the left if we wished to continue on the main line, and towards the right if we wished to enter the branch.

There is no difficulty in doing this when there is only one waggon to handle; but it is preferable to have switches, or at least one switch, when the waggons are in trains. The driver of the horse, who then goes in front of the train, shifts the switches to suit the direction in which he wishes to travel.

(387) The systems described above are more or less analogous to those of ordinary railways, although the crossings and switches are constructed in a simpler manner, the latter, as well as guard-rails, being occasionally entirely discarded. A further simplification consists in replacing them by a *turn-plate.*

This system is especially suitable when the angle at which the branch and the main railway meet each other is very marked, when the width of the galleries does not admit of sufficient room being

given to the curve, or when it is desired to establish a network of railways at a point where there are pillars. We must consider each crossing as the starting-point of four lines of rails, and that we wish to be able to pass from any one of the roads into each of the other three.

In the case of a railway on the large scale, the ordinary proceeding would be to put down a turn-table at this point; but this is not a feasible solution for a mine. These turn-tables would be too costly, too difficult to set up, and too many of them would be required.

The true way of meeting the difficulty is to lay down a *turn-plate,* which consists in placing either cast iron plates resting on a carefully-laid wooden frame in the cross-way, or a platform of strong planks on which the four lines of rails terminate. The central space of the turn-plate remains clear to allow of the waggon being turned, so as to bring it opposite the line of rails which it is intended to follow. Some ridges cast on the iron plates, or made of bars of iron, and fixed to the platform, serve the purpose of directing the wheels of the waggon in such a way that they cannot miss the rails. (See fig. 269.)

Very frequently the platform is also furnished with a circular rib of iron in the middle, of a diameter rather less than the gauge of the railway (fig. 270); and this arrangement facilitates turning the waggons in any desired direction, so as to bring them opposite to the line of rails which they are intended to enter upon.

The employment of platforms of this kind is convenient at branchings of the roadways, at sidings, or at the points where the trains are formed or broken up.

Turn-plates cannot be used with advantage unless the rolling stock is light and easily handled, and the wheels are movable on the axles, which are themselves fixed. This is the reverse of the plan adopted for large lines.

The numerous reasons which justify this great difference between the rolling stock of underground railways and that of great lines at the surface will be perceived as we proceed with the subject.

(388) The question of choice of rolling stock for underground workings is a very important one; and one great reason for examining it in detail is that the answer to it, in our opinion, depends upon considerations which are *different* from those which influence us in choosing rolling stock for a great line at the surface, or, to speak more to the point, the considerations are, *in some respects*, exactly *the reverse.*

The universal practice for the last thirty years, on the great lines, has been to increase the size of the waggons. Thus, for instance, the first coal trucks were made to hold only 1½ ton (1,500 kilog.), and the load was increased to 2½, 5, 6 tons (2,500, 5,000, 6,000 kilog.) successively, until now, at the present day, it often amounts to 8 and even 10 tons (8,000 and 10,000 kilog.). This is done because the mineral is carried to great distances; and there is no difficulty about getting room for the waggons, at least within certain limits, nor in shunting them at the stations and, lastly, the increase in the size of the waggons diminishes the amount of work to be done in making up or subdividing trains.

In a mine the circumstances are quite different.

In the first place, it is an advantage to have the galleries small, in order to diminish their first cost, and, what is more important, the cost of keeping them in repair.

Besides, it is necessary, when one of the waggons runs off the rails—and this often happens—that the haulier of the single waggon, or of the train to which it is attached, should, by himself alone, be easily able to replace it on the rails without sensibly retarding the traffic.

Finally, another reason, and in our opinion one of paramount importance, for making the rolling stock light is, that young people, or almost children, may be able to handle it, and that work may thus be found for them at an early age. In this way, while assisting their families by their earnings, they gain a practical knowledge of their calling, and so fit themselves for by-and-by undertaking work which can only be performed by full-grown men. It is as necessary that there should be young people, or almost children, in a mine, as it is that there should be cabin-boys and apprentices in a ship, and in the actual state of affairs

everything that tends to augment their number in the workings is to be recommended.

(389) Next to the question of size, the question of type of waggon presents itself.

Three essentially distinct types can be distinguished:

1. Waggons which are filled in the working places, or near them, and emptied at a *lodge* or *plat*, or at the bottom of the shaft.

2. Trolleys for carrying kibbles, baskets, or boxes of any form These boxes are filled at the faces, drawn sledge-fashion to the place where the tram or trolley is situated, placed on the tram, conveyed on it to the bottom of the shaft, and then raised to the surface alone.

3. Lastly, waggons which are loaded at or near the working places, and conveyed thence to the surface, thereby avoiding any kind of transhipment of the mineral.

In our opinion, the first system may be regarded as obsolete, as far at least as regards the working of coal. Indeed, after having been almost universally employed for about forty years, it is now almost entirely abandoned. Its principal defects are, that the coal is broken by the numerous transhipments to which it is subjected during its transit, and that there is no chance of recognizing whence any of the coal comes when it arrives in the kibble at the surface. It is consequently impossible to exercise any control over the hewers, and to make them interested to some extent in a most important question, namely, the state and cleanness of the coal which leaves their working places. There is, in our opinion, only one circumstance which might possibly justify the adoption of this system, and that is, if the mineral were too irregularly distributed, or the seam too thin, to make it worth while going to the expense which would have to be incurred in establishing a proper system of haulage with waggons of sufficient capacity.

The system of having trolleys carrying kibbles or boxes admits of a combination of sledging and tramming in the same workings. If, therefore, in a given mine there is a district in which the conditions are unfavourable to haulage, with a variable or irregular dip, or with a series of faults producing numerous changes of level

in various directions, it may be expedient to have railways in only one or two galleries which are sufficiently regular to admit of their construction, and to do the haulage of the working places adjoining them by means of sledging. Sidings can be made in these galleries for the trolleys which will receive the baskets or boxes as they are sledged down.

In this manner the cost of the rolling stock can be diminished; but there is always a large proportion of dead weight to be handled for a given quantity of mineral, and the system is incompatible with an active haulage.

Rolling stock which is filled in the working place, and emptied at the surface, is more expensive to introduce and keep in repair, especially if, profiting by the facilities which it presents for this purpose, it is conveyed away to a considerable distance from the winding shaft. But if the shaft is well adapted for it, and if the seam is regular, and presents facilities for disconnecting trains of empties on their arrival at certain points in the galleries in order to distribute them quickly and easily among the adjoining working places, it will be found to possess the advantages of rapidity, economy in manual labour, the suppression of transhipments, and lastly, the two *advantages of vital importance* already referred to—that of the possibility of recognizing the origin of the coal on its arrival at the surface, and that of being able to employ a number of young people or children in the interior of the mine.

This system, it is true, has the defects already referred to, that it is expensive in first cost, and that there is more dead weight to be supported by the winding ropes for a given weight of coal. These disadvantages, however, do not by any means balance the advantages pointed out above; and, indeed, this is the system which prevails *in all places where it is applicable* at the present day, as is the case, for instance, in the extensive mines of England, where the beds of coal are of medium thickness, of regular lie, and in a nearly horizontal position.

Thus in the large coal mines near Newcastle, the same tubs which are drawn through the galleries in long trains by horses or engines are distributed among the working places of a district by ponies driven by children.

These tubs are made as low as possible, to enable them to be taken everywhere with ease, and at the same time to render the work of filling them less difficult. Their wheels are sometimes not more than 8 inches (20 centimetres) in diameter. The tub weighs 2½ cwt. (150 to 200 kilog.) at the most, and its ordinary load is generally less than 10 cwt. (500 kilog.), and sometimes only 6 cwt. (300 kilog.). With weights of this kind the haulier can manage to replace a tub on the rails. Nevertheless, the largest of these tubs are already heavy enough to make it difficult to handle them with the necessary speed at the hanging-on-place, and the *hitchers* or *onsetters*, therefore, require to be exceptionally strong men, on account of the large outputs which are customary in England.

Sometimes arrangements are made for enabling the tubs to run along the ordinary floor of the galleries as well as on rails. By adopting this plan the ordinary working places which are not provided with railways can be served by the ordinary tubs without the use of special stock to convey the coal from the face to the railway. The modification consists in making the flange as wide, or nearly as wide, as the felly itself. These little wheels are known as *roulettes* in French, and the tubs which have them are called *wheeled tubs*, to distinguish them from *sledge-tubs*, and they have the advantage over the latter of being more easily handled. The employment of wheeled tubs is very convenient, and is practised with success in various localities, and notably in the district of the Loire.

(390) From what has just been said, we shall assume that the tubs contain at least 6 cwt. (300 kilog.), and at most 10 cwt. (500 kilog.) of coal; and that the loaded tub weighs 9 to 14 cwt. (450 to 700 kilog.), according to the dimensions of the galleries, and the age of the young persons who are to be employed in the work of haulage.

Rolling stock of this size will readily pass through galleries of comparatively small section, which generally have the advantage of being easily kept in repair.

If, however, local conditions allow the levels to be made suf-

ficiently large, it may be thought advisable to take advantage of the possibility of using larger waggons. This is the reason that in some mines the tubs weigh from 1 ton to 24 cwt. (1,000 to 1,200 kilog.) when filled.

But these large waggons should not be adopted unless we feel certain that the deposit is sufficiently regular to allow the railways to be laid without many ups and downs, since, as we shall see further on, a gallery with varying gradients is badly adapted for the employment of such a heavy rolling stock. It is expedient moreover, even with waggons of this exceptionally heavy construction, to employ children in couples to do the haulage rather than full-grown men.

We think it a highly important rule in mining *to make the children or young persons do all the work in a mine which does not necessarily require to be done by men.*

(391) Having considered the questions of size and type of construction, we have still to turn our attention to various other points; especially as to what general shape the tubs should have; whether they should be made of wood or iron; and lastly, what system should be adopted in the construction of the wheels and axles.

Regarding the first point, we may distinguish waggons with a horizontally rectangular section, similar to large railway trucks, and those which are elliptical, like a tub.

The tram-waggons of the Newcastle district are of the former shape, and the *wheeled tubs* of St. Etienne of the second.

The former shape has an evident advantage, because, with given dimensions as to height, length, and width, it has a greater capacity than the other.

Let h, l, and l' represent these three dimensions, which depend upon the size and gradients of the gallery in which the tubs are to circulate. The volumes will be respectively $V = hll'$ and $V' = h\pi\frac{ll'}{4}$; the ratio of V' to V is $\frac{\pi}{4} = 0{\cdot}7854$. We thus lose more than 20 per cent. of the useful space by employing elliptical tubs instead of rectangular boxes. The latter should, therefore, be

preferred if the decision is to be influenced by the narrowness of the galleries. If, however, on the other hand, the amount of the load is unlimited, except by considerations respecting the age of the children to be employed in handling them, the question assumes a different aspect. It might be thought at first sight that well-hooped tubs would most effectually resist the various shocks to which the boxes are exposed, both during the transport and when being emptied, and also that in case of damage they could be more easily and cheaply repaired. Nevertheless, it does not appear that there is any important difference in these respects.

(392) In regard to the choice to be made between metal and wood, the practice of most mines is in favour of the latter material; and this is the case even in England, notwithstanding the scarcity of timber, the low price of iron and its habitual employment in that country. We may fairly assume that the small mine waggons will continue to be constructed of wood for a longer time than the large railway trucks, because we can afford to make the latter in a relatively more careful and costly manner; and, besides this, there is more likely to be a dearth of timber for them, as larger pieces are required. In certain mines, however, the tubs are made entirely of iron (bar iron, sheet iron, and cast iron), especially in those which are in connection with, or in the immediate neighbourhood of, ironworks, as then the worn-out waggons can easily be worked up as scrap.

We could also instance several cases in which the framework is of wood and the box of sheet iron. It may be imagined, however, that this arrangement is not a very rational one; for the sides and bottom of the box are the parts which are most liable to be knocked about and broken, and at the same time they are the very parts which can be most cheaply and easily repaired when they are made of wood.

Iron waggons have nearly the same amount of dead weight as wooden ones, and the cost per unit of weight is also *nearly* the same. It is possible, however, that iron tubs may be somewhat lighter, and their price somewhat greater; on the other hand, we may assume that they are not so easily repaired, and that

they require for this purpose workshops more carefully fitted up.

In conclusion, we may say that the comparison of the two systems does not indicate any very decided reasons for preferring one above the other, but that the employment of wood seems to be advisable in mines which are worked on too small a scale to be provided with well-furnished workshops; whereas, in the case of extensive mines with well-appointed fitting-shops, reasoning seems to suggest, and experience to confirm it, that the two systems may be employed *almost indifferently.*

(393) Lastly, as regards the connection between wheels and axles, the question presents itself as to *whether the wheels should be keyed on to movable axles, or the axles themselves be fixed while the wheels can revolve on them.*

It will be remarked at once that the former system is *universally* employed on large railways, and that the latter is *quite as exclusively* used on ordinary roads.

The reasons which conduce to the adoption of each system in its own case are easily understood.

In the first place, two wheels keyed on to an axle are like parallel sections of the same cylindrical surface rolling on a pair of rails, which we suppose to be straight (curves will be referred to further on), and have a tendency to remain on the rails with a great degree of stability. Besides, in consequence of the width between the bearings, the small inequalities produced by wear between the journals and their brasses make but a very slight alteration in the originally horizontal position of the axle, or what is the same thing, they do not cause the wheels to deviate much from the vertical planes in which they should move.

A given amount of wear will produce a much smaller deviation with fixed wheels than with those which revolve on the axles, because the naves of the latter are necessarily limited in length.

In the second place, carriages running on ordinary roads have to turn aside constantly to avoid collisions; they have, moreover, to turn round sharp corners of streets, or even to wheel round 180°

on the spot, in order to return over the ground they have already traversed.

During these movements the arcs traversed by the circumferences of the two wheels may be unequal; one may be zero if the carriage is pivoted on the point of support of one of the wheels; or the two may be equal and in opposite directions if the carriage is turned on its centre of gravity. If the wheels are independent, these movements can be easily made; but if, on the contrary, the wheels are keyed on the same axle, they cannot be made without a certain amount of sliding on the part of one or other of the wheels, or of both at the same time. In the latter case, the total amount of sliding is equal to the algebraic difference of the distances traversed by the two circumferences, considering the movement forwards as positive, for example, and the movement backwards as negative.

Thus *an ordinary carriage* can be turned round on the spot without encountering any resistance except that caused by the friction of the naves on the journals, which is in proportion to the radius of these naves—the resistance to the rolling motion of the felly is here neglected. A *railway waggon*, on the other hand, cannot be turned in the same way without being changed into a *sledge*, at least for half its weight, if the wheels are equally loaded; and this sledge must slide through a distance equal to the difference of the arcs described, a quantity which is greater than the amount of sliding of the nave on the journal in the ratio of the radius of the axle to the radius of the wheel. In other words, a given force which could easily turn on the spot a carriage with the wheels loose on the axles, would be quite unable to accomplish the same movement with a carriage fitted with wheels keyed on to a movable axle.

(394) There is another remarkable difference between the two systems of wheels, when, as usually occurs, the drawing or pushing force does not act in a plane which passes vertically through the centre of gravity of the loaded waggon.

As the simplest case in point, we shall consider a single axle loaded with a weight which gives rise to the pressures P and P′ on the two wheels. Let R be the radius of the wheel; r that of the

nave if the wheels be movable on a fixed axle, or of the axle if the wheels be fixed to a movable axle; f the proper coefficient of friction for the naves or the axle; T the horizontal effort of traction, which is very small in proportion to the weight P and P′ with which the wheels are loaded; Q and Q′ the rolling friction of the wheels on the rails; and lastly, f' the sliding friction of the wheels on the rails when there happens to be a sliding motion.

We shall suppose the waggon to be moving along the rails with a uniform motion of translation, and the wheels to be rolling without any sliding.

We have then the following relations:

$$T = Q + Q', \tag{1}$$

which expresses the uniformity of the movement of translation;

$$Q < f'P,\ Q' < f'P'; \tag{2}$$

showing that the wheels do not slide on the rails; and lastly,

$$(Q + Q')R = fr(P + P'), \tag{3}$$

which (disregarding the influence which the force T exerts on the pressure which causes the friction of the axle) expresses the equilibrium of rotation of *the system composed of the two wheels keyed to a movable axle;* or,

$$\left.\begin{array}{l} Q\,R = frP \\ Q'R = frP' \end{array}\right\} \tag{3'}$$

which express the fact that each *of the two movable wheels is in equilibrium on its own fixed axle.*

From the two equations of (3′) we can deduce a last one—

$$\frac{Q}{Q'} = \frac{P}{P'} \tag{4}$$

Thus in the first case the two forces Q and Q′ remain undetermined since only their sum enters into the equations (1) and (3), and since they have merely to satisfy the inequalities (2).

In the second case, on the contrary, they are perfectly determined by the two distinct equations of (3′) which replace the single equation (3).

Equation (4), which is deduced from (3′), shows that the re-

sultant of these two forces divides the distance between the two wheels into two parts, which are inversely proportional to the weights P and P′; that is to say, it is *in a vertical plane which passes through the centre of gravity of* $P + P'$. It is therefore necessary, in order to keep the waggon in equilibrium, that the force T be in the *same* plane; for otherwise the external forces T Q, and Q′ would give rise to a horizontal couple tending to turn the waggon round a vertical axis.

If this condition is not fulfilled, the waggon is constantly tending to deviate from its position on the rails, and can only be prevented from doing so by suitable transverse forces developed by the motion, or at the points of contact between the wheels and the rails.

In the first case, on the contrary, the vertical plane in which T is situated does not necessarily require to pass exactly through the centre of the figure; or, in other words, the waggon may be loaded unsymmetrically within certain limits without giving rise to this tendency to deviate. It must be understood, however, that in this case the two arbitrary forces Q and Q′ *accommodate themselves* to the circumstances in such a way as to give a resultant in the same vertical plane as T.

Thus, summing up what has been said, a waggon may be made to run regularly along a railway, although the force which propels it is not symmetrically applied; for example, by a force applied to one of its buffers; whereas, in order to propel an ordinary vehicle regularly on a common road, it is necessary that the force be made to act in a plane passing exactly through its centre of gravity.

(395) The reasons set forth above amply justify the arrangements universally adopted in practice, *on the one hand*, for the plant of railways, *on the other*, for ordinary carriages.

To which of these two practices ought one to adhere in the case of railways in mines?

We have now to examine this question.

In so far as it is a question of running in a straight line, the system on which large railway waggons are constructed retains all its inherent advantages when applied to small waggons or tubs.

These are, the vertical position of the wheels, and the greater degree of stability of the waggon on the rails. On the other hand, however, if the waggon has to be handled on turn-plates, or if it has to run anywhere along the floor of the gallery, like wheeled tubs, movable wheels on fixed axles present important advantages, from the greater facility with which they enable the tub to be turned about. These advantages must lead us to decide in favour of this latter system when the waggons are heavy; and its disadvantages are not of the same importance as they would be on a large railway devised for passenger traffic, where the speed is much greater, the waggons heavier, and the consequences of running off the rails infinitely more serious.

In reality there are many well-managed mines, such as those in the Newcastle district, in which the wheels are, for the most part, fixed on the axles of the tubs; but in others, and more especially where wheeled tubs are employed, the wheels are, on the contrary, movable on a fixed axle. In our opinion this system ought usually to be preferred in France, where the seams are less regular, and the workings less extensive, than in many of the English districts. We imagine that the system which prevails at Newcastle is adopted on account of the mechanical haulage usually resorted to in that district, which involves serious consequences when a waggon accidentally gets off the line.

(396) There is yet another consideration of which we have not hitherto spoken, namely, *that of curves*, which, as we shall presently see, may induce us to prefer the second system.

In what precedes we have supposed the roads to be straight. The presence of curves influences both the railway and the rolling plant at the same time. In this respect also there is an essential difference between curves of large radius, such as those of railways at the surface, and the curves of small radius, or even sudden bends, which are to be met with in mines.

In order to appreciate the difference between the cases, it is necessary to consider what takes place when a train is running over a curve situated between two straight parts of the line.

In the first place, the distance traversed on the rail situated on

the convex side of the curve, is greater than on the other rail; as a consequence, if the wheels are fixed on the axles, an unavoidable sliding must take place, the extent of which is equal to the difference of the distances traversed on the two rails. If we put a as the angle at the centre of the curve or the angle between the two straight parts, R, the mean radius of the curve, and $2l$ the width between the rails, then the length of the exterior arc is $(R+l)\,a$, that of the interior one $(R-l)\,a$, and the amount of the sliding $2\,l\,a$; that is to say, it increases with the width between the rails for a given angle at the centre.

The ratio of the sliding to the mean space traversed, R a, is equal to:

$$\frac{2la}{Ra}=\frac{2l}{R}.$$

This quantity, multiplied by the ratio $\frac{f'}{f}$ of the coefficients of friction at the tire and at the axle, is a measure of the increase of work done against the friction produced while the curve is being traversed. It increases directly with the width of the way, and inversely with the radius of the curve. This increased resistance, and the wear and tear of the tires and rails produced by it, are altogether avoided when the wheels are loose on fixed axles. Each wheel then rolls *independently* on its own rail, the exterior wheel turning somewhat more rapidly than the interior one; but their mean velocity is the same as if they both ran along the axis of the curve.

In the second place, if one of the axles is properly situated, that is to say, at right angles to the rails, the other is necessarily oblique, and at the same time if the first pair of wheels is correctly placed on the rails, that is to say, tangentially to the curve, the other pair has a tendency to get off the line, the flange of the exterior wheel tends to cut into the rail, and the flat part of the tire of the other to fall into the space between the rails. These results are at once rendered evident by the simple inspection of a diagram.

In the third place, this constant change of the position of the axle, so that it may remain at right angles to the rails, may cause,

or be caused by, the friction of the side of the flange of the outer wheel on the inside of the rail.

In the fourth, and last place, the action of centrifugal force, together with that of inertia, produces, or tends to produce, the effect just alluded to; namely, the friction of the flanges of the wheels on the outer rail.

(397) The various arrangements that have been proposed, or that may be adopted, to counteract the foregoing irregularities, are as follows:

As regards the unequal distances traversed on the outer and inner rails of a curve, we have seen that this inequality decreases with the width between the rails; narrow gauges are, therefore, preferable in mines, not only because they permit the section of the galleries to be reduced, but also because they diminish the resistance due to a curve of given radius. At the same time there is an inferior limit to this width, determined by the condition of not having the body of the waggon too narrow, since its other dimensions would then require to be enlarged to an inconvenient degree, and by the condition of retaining sufficient stability transversely.

In practice, as we have already said, the gauge is never less than 18 inches ($0^m.45$.)

If it is desired to lessen or even to do away with the sliding of the periphery, due to the inequality of the distances traversed by the two wheels, the most natural remedy, and the one whose advantages are all the more obvious as the curvature increases, is to have the wheels loose on fixed axles, according to the system described in a preceding paragraph.

A system of *half-fixed* wheels has also been employed, consisting of one wheel keyed to a movable axle, while the other is loose on the same axle. On a straight part of the railway the system behaves in the same way as if both wheels were keyed; but on a curve, when otherwise one wheel would slip on the rail, the loose wheel turns to a small extent on the axle, and the friction of its tire on the rail is replaced by the friction of its nave on the axle; this absorbs less work, since, as we have already said, the co-

efficient of friction, and the space through which it acts, are very much less in this case.

This arrangement has been employed for railways of secondary importance with many sharp curves, rather than for the railways of mines properly so-called.

A third means consists in employing a separate axle for each wheel, and then two parallel axles placed side by side carry two wheels keyed to them, one at the left-hand extremity of one axle, the other at the right-hand extremity of the other. This system affords a complete solution of the question; but it is somewhat complicated, it augments the dead-weight, and it increases the work and expense of lubricating. It has been employed sometimes, however, and notably so at Saint Etienne, in the construction of trolleys for carrying tubs or corves.

Lastly, a fourth means, which at the same time permits all four wheels to place themselves tangentially to the rails, is to have each running in a block movable round a vertical axis. There are thus four axles, fixed two and two, in each of the main beams of the waggon-frame.

This system is not to be recommended; for besides raising the body of the waggon too high for a given radius of wheel, it appears to us to be too complicated and too difficult to keep in repair; and it does not sufficiently well resist the numerous shocks to which the wheels are exposed in practice.

(398) To remedy the second defect, mentioned in No. 396, viz., the necessarily improper position of one of the pairs of wheels on the rails, we may employ either the system of wheels running in blocks, mentioned above, or an arrangement which permits the axles to adjust themselves to the curve in such a way that the prolongations of their axes meet in the centre of the curve.

For this purpose, without adopting the complicated system invented by Arnoux, which would not be applicable in this case, we might simply support the box of the waggon directly on the axles by means of pivots introduced into sockets in its bottom, and in which they can turn freely. According to this system it is not each wheel, but *each pair of wheels*, that can turn about a

vertical axis in such a way as to place itself at right angles to the curve. It is to be understood that the wheels are movable on the axle, and that the body of the latter is flat, so as to carry the box of the waggon which rests on it. The axle in this case makes only a slight angular movement on its pivot relatively to the box of the waggon.

This plan is satisfactory enough, although perhaps it leaves something to be desired as far as solidity is concerned. It is analogous to the system adopted on American railways, where very long cars have to run over sharp curves.

It is the only arrangement which affords a geometrical solution of the problem of placing the two axles of a waggon *properly* on a curve. Every means which preserves the parallelism of the axles is only a partial remedy, since *on a curve* it is impossible that two parallel axles can both point radially towards the centre as they ought to do. It is, moreover, obvious that the position of the axles will be less irregular as the curvature decreases, or its radius increases, or as the axles themselves are brought closer together.

The radius of curvature is, however, limited by the condition that the rails must follow the galleries, a circumstance that does not permit the adoption of easy curves like those employed above-ground. It is often necessary, for instance, to turn at right angles in mines in order to pass from a cross-cut into a level, and at such a point it is not always expedient to cut too deeply into the corner of rock on the concave side of the curve. This circumstance determines the least radius of curvature possible in mine railways.

The calculation is as follows:

Suppose that A C and C X (fig. 271) are the axes of the two roadways, at right angles to each other, along which the waggon has to be taken, and that A′ C′ X′ is the side of the two galleries before any cutting takes place. The two lines of rails will be joined by an arc of a circle whose centre is situated in a point O, which remains to be determined, and the corner of the pillar ought to be cut with a circular profile having the same centre.

This amount of cutting is equal to the quantity C′ D according to the figure.

Let R be the desired radius A O; L the quantity A A′, the half-width of the gallery; e the amount of cutting C′ D.

Then we have evidently—

$$C'D = C'O - OD = A'O(\sqrt{2} - 1),$$
$$\therefore \quad e = (R - L)(\sqrt{2} - 1),$$
$$e = 0{\cdot}41(R - L);$$

from which we may deduce the amount of cutting to be done for a given radius when the gauge of the line is known, or inversely the radius that should be taken in order to avoid having more than a given amount of cutting. It is this condition of having to keep within a certain limit for e which compels the radius R to be diminished in practice. If a large radius were adopted, too wide a space would have to be provided when a road branched off.

If, for example, we put $e = 3$ ft. 3 in. (1^m), L = 2 ft. 8 in. ($0^m.80$), the gallery being therefore 5 ft. 4 in. wide ($1^m.60$), we shall find

$$R = \frac{39}{0{\cdot}41} + 32 = 127 \text{ in.} = 10 \text{ ft. } 7 \text{ in.} \left(\frac{1}{0{\cdot}41} + 0{\cdot}80 = 3^m.23\right).$$

Curves of a radius as small as this, or even smaller, are used in practice; but such radii are evidently extremely small compared with those adopted for large railways.

The smallest distance between the axles is limited by the diameter of the wheels themselves, and in this extreme case the wheels would be tangential to each other. This limit is approached as closely as possible consistently with giving sufficient stability to the waggon lengthwise. This arrangement has one advantage, in allowing the trammer or haulier to replace the waggon on the rails more easily than if the axles were further apart. The operation is performed by lifting one end; and it is evident that the ease with which this can be done increases with a given weight in proportion as the waggon is longer, and the axles more nearly approached to the centre of gravity.

Even when the radii of curvature are as great, and the axles as close together as possible, there is still another point requiring consideration, namely, that care must be taken to make sure that the four wheels on the two axles *can be inscribed in a proper manner in the interior of the space bounded laterally by the internal faces*

of the two rails, due allowance being made for the radius of the wheels, and height of their flanges. For this purpose it is necessary to make a drawing on a large scale, showing the details both in plan and elevation.

It is easily seen that, in order to fulfil this condition, certain provisions must be made in the details.

Thus it is necessary:

1stly. To make the curved part of the railway somewhat wider than the rest, or to allow a decided longitudinal play to each pair of wheels on the rails of at least one inch (25 to 30 millimetres).

2ndly. To have the flat part of the tires sufficiently broad, 2 to 2½ inches (50 or 60 millimetres) at least.

3rdly. Not to have the flange higher than is strictly required to guard against over-riding, one inch (25 to 27 millimetres) at most.

The object and effect of these arrangements are to prevent the outer wheels from overriding the rails towards the outside, and the inner ones from falling into the inside of the space between the rails, and to hinder the flanges of the outer wheels from cutting into the rails.

A fourth contrivance is added to these, and that is, to make the periphery of the tire slightly conical. The object of this is two-fold; namely, to increase the stability of the waggon on straight parts of the railway, in spite of the longitudinal play of the wheels, and to facilitate the traversing of curves. It is easy to conceive how these two results are obtained by the conical form of the wheels when they are keyed on their axles.

If we suppose, for example, that the waggon deviates appreciably from the axis *on a straight part* of the railway, say to the right-hand side, then the radius of the wheels on the right-hand side is enlarged, and that of those on the opposite side diminished. When the axle on which the wheels are keyed has, therefore, passed through a given angular space, the former wheels will have described a larger arc than the latter, and, therefore, the waggon will have been immediately brought back to its proper position, being carried towards the left-hand side.

On a curve, the inertia of the mass throws it towards the rail situated on the convex side, and a similar effect is produced,

which constantly tends to bring back the waggon towards the concave side. Knowing the conicalness of the wheels, measured by the tangent of the angle α, which the generatrices of the cone make with the axis, the radius R of the wheel at the middle of the tire, and the width of the gauge $2l$, we can easily find x, the proper amount of extra width of gauge for traversing a curve of the radius ρ. On the convex side the radius R will become $R+x \tan \alpha$, and on the other side it will be $R-x \tan \alpha$, the difference of these radii is thus $2x \tan \alpha$, and the condition of having a cone whose apex is at the centre of curvature will evidently give the relation:

$$\frac{2x \tan \alpha}{2l}=\frac{R}{\rho};$$

whence we deduce:

$$x=\frac{lR}{\rho \tan \alpha};$$

that is to say, the extra width will increase with the size of the gauge and the radius of the wheels, and will vary inversely as the radius of the curve and the degree of conicalness.

The system of conical wheels has led to another plan known as Laignel's system, from the name of the inventor. It consists in making the outer wheel run on its flange in passing round curves, while the interior one runs, as usual, on its rim.

Calling ρ the radius of the curve described by the axis of the railway, $2l$ the width of the gauge, and h the height of the flange, we shall express the fact that the conical surface, which bounds the flange of the exterior wheel and the rim of the interior one, has its apex at the centre of the curve, by laying down the equation:

$$\frac{R+h}{R}=\frac{\rho+l}{\rho-l};$$

whence we deduce:

$$\frac{h}{R}=\frac{2l}{\rho-l};$$

that is to say, that the flange of the wheel should bear the same proportion to its radius that the width of the railway does to the radius of curvature of the inner rail.

It is plain that this system would often lead to the necessity of having inconveniently high flanges where the curves are sharp;

and it has further the disadvantage that it is only applicable to curves of a given radius. It is, therefore, not to be wondered at that it has not met with the success one would have been led to expect, judging by the manner in which it was taken up at first.

(399) Lastly, in addition to the other expedients, we have to mention the one which consists in having the two rails at different levels on a curve.

The mode of applying this principle may depend on the manner in which the waggons are propelled.

Looking at the question in this light, it is easy to see that if the waggons are moved by a *pulling* force as they enter upon a sharp curve, they will tend to run off the rails towards the concave side; while, on the other hand, if it is a *pushing* force, they will tend to run off on the opposite side; and thus there will be a certain advantage obtainable by raising the rail somewhat on the side towards which the tendency to running off exhibits itself.

We should thus raise the *inside rail,* in those parts of a railway over which trains of waggons are hauled by horses, and the *outside rail* where they are pushed one by one by putters.

There is, however, a reason of a different kind which makes it preferable to raise the outside rail, particularly where the waggons are travelling with great speed on curves of small radius. The principal object to be overcome, in a case of this kind, is the centrifugal force which tends to throw the waggon towards the outside of the curve. For this purpose the exterior rail is raised to a certain extent, which places the waggon at each instant, as it were, on an inclined plane across the railway, perpendicular to the resultant of the centrifugal force and the force of gravity, to which its whole mass is subjected.

Designating the total weight of the waggon by P, its velocity by V, the width of the gauge by 2 l, and the mean radius of curvature by ρ, the required elevation of the outer rail, h, will be given by the equation:

$$\frac{h}{2l} = \frac{\frac{PV^2}{g\rho}}{P};$$

whence we have:

$$h = \frac{V^2}{2g} \times \frac{4l}{\rho};$$

that is to say, the degree of elevation h is the height which would generate the velocity V reduced in the proportion of twice the breadth of the road to the radius of curvature.

For example, if $V = 3$ ft. 3 in. (1 metre), which would be generated by falling through a height of about 2 in. ($0^m.05$); if $2l =$ 2 ft. 4 in. ($0^m.70$), and if $\rho = 8$ ft. 2 in. ($2^m.50$), we have $h = 1\frac{1}{8}$ in. ($0^m.028$).

This theory is applied in the construction of all important railways, and it is well known that in passing round curves the transverse inclination of the carriages is quite perceptible to the passengers. The term with V^2 is much greater than on a mine railway; but, on the other hand, the factor $\frac{4l}{\rho}$ is much smaller, and thus the height h still amounts to an inch or more in most cases.

(400) The foregoing are the various theoretical considerations that have to be borne in mind, so far as the *projection in plan* and *the curves* are concerned, when railways and rolling stock have to be designed for any given mine.

We must now consider the *longitudinal section* of the line; that is to say, we must study the question of gradients.

It is known that the resistance to rolling on a level railway is not generally more than *a few thousandths* of the weight moved or carried. The consequence is, that a variation of a few thousandths in the rate of the slope may produce a great difference in the resistance to be overcome.

An upward gradient, which is hardly perceptible to the eye, may be sufficient to double or treble this resistance.

A downward gradient, which is equally slight, may greatly reduce, or entirely destroy, this resistance; or it may even make the waggons tend to descend of themselves, so that it would be necessary to *hold them back* in order to moderate their speed, rather than to *push them* in order to maintain it.

In laying out the inclined parts of a tramroad, it is important therefore to settle the gradients with great care; and the necessity for this care increases as the resistance on the level diminishes and as the line and waggons are better made.

The resistances are easily calculated.

Assuming that the resistance developed at the rim of the wheel does not absorb any part of the work, a supposition that more nearly approaches the truth as the speed is less, and the construction of the railway more perfect, we shall have in a general way, in the case of a waggon moving at a uniform velocity, to establish equilibrium between the drawing force, gravitation, and the friction of the axles.

Denoting by P the useful load of the waggon;

By P′ + P″ the *dead weight*, or the total weight of the empty waggon, composed of the weight P′ of the body, or, more generally, of the parts that only participate in the movement of translation, and of the weight P″ of the wheels, or of the whole of the parts that revolve with them;

By f the coefficient of sliding friction, corresponding to the nature, the degree of polish, and the state of lubrication of the surfaces in contact, whether they consist of movable wheels on fixed axles, or of movable axles working in bearings;

By r the radius of the movable piece (nave or axle) which rubs against a piece invariably attached to the waggon (spindle or brasses);

Lastly, by R the radius of the wheels;

The resistance on the level will be given by the known equation:

$$\phi = \frac{f}{\sqrt{1+f^2}} \frac{r}{R} (P+P'),$$

a formula in which the small value of the coefficient f permits, as we know, of our putting f for $\frac{f}{\sqrt{1+f^2}}$, with a relative error which is sensibly equal to $\frac{f^2}{2}$.

For the purpose of simplifying it then we shall write it as:

$$\phi = \frac{fr}{R}(P+P'),$$

which is a sufficiently close approximation for the calculations with which we are now engaged.

On a part of the road with a gradient i, the action of gravity will have as a general expression:

$$\phi' = (P + P' + P'') \sin i,$$

and it will always act in the direction of the slope. It will increase or diminish the force ϕ, therefore, according as we consider the waggon drawn up an acclivity or let down a slope.

The force ϕ itself ought to be considered as a constant quantity, not changing its value in passing from a level to an inclined road; because, since it is very small, and the gradients in question are very slight, the pressure which determines the friction is not sensibly altered, either by the force ϕ, or by the force ϕ' produced by the inclination of the road. Therefore, for an ascent the total force of traction will practically be:

$$F = \phi + \phi' = \frac{fr}{R}(P + P') + (P + P' + P'') \sin i, \qquad (1)$$

and for a downward slope:

$$F' = \phi - \phi' = \frac{fr}{R}(P + P') - (P + P' + P'') \sin i. \qquad (2)$$

These same formulæ are applicable either to *full* or *empty* waggons, according as we give a certain value to P or make $P = 0$.

These formulæ, which virtually afford the solution of the various questions that may be proposed regarding the gradients of a railway, give rise to certain observations.

It is evident, in the first place, that, everything else remaining the same, the forces F and F′ will diminish as the product $f\frac{r}{R}$ becomes smaller; in other words, it is necessary to diminish each of the two factors of this product. The coefficient f, or the intensity of the friction, should be lessened by having well-polished and properly-lubricated surfaces; and the factor $\frac{r}{R}$ should be reduced by making the radius of the wheel *as great as*, and

the radius of the nave, or of the spindle of the axle, *as small as* possible after taking into account the forces at work, and the most suitable materials, the various considerations as to weight, dimensions, etc.

This is the *verification*, for the case in point, of the general observation made in Nos. **29** and **30** of the *Cours des machines*.

In reality the radius R is limited within very narrow bounds by the condition that the waggon must not be too high lest its stability be reduced, the work of filling it made difficult, or the height of the galleries become too great; and the radius r must not be made too small for fear of rendering it too weak.

On the other hand, mine waggons are generally only imperfectly lubricated, and their friction is increased sometimes by the dust, and at other times by the mud that is splashed upon axles placed too near the floor.

The product $f\frac{r}{R}$ may, therefore, be considered as being much *greater* in the case of small mine waggons than it is in the case of ordinary large railways.

We may take the value of f as 0·1. For the quantity $\frac{r}{R}$ we may take about the same amount, or *rather more* for very small wheels of 8 to 10 inches($0^m.20$ to $0^m.25$), and about the same value, *or rather less*, say $\frac{1}{12}$, for wheels of 20 inches ($0^m.50$), which are the largest size employed in mines.

We may admit, therefore, that the mean value of the coefficient $f\frac{r}{R}$ is equal to 0·01, which would be much too high for the rolling stock of large railways.

In each particular case the values of P, P′ and P″ will be known. But we may admit that in round numbers we shall generally have $P' + P'' = 0{\cdot}40$ P, and between P′ and P″ there is a somewhat variable ratio according as the axles are fixed or movable.

Supposing $P' = 2{\cdot}5\ P''$, we shall find that in round numbers

$$P' = 0{\cdot}29\ P.$$
$$P'' = 0{\cdot}11\ P.$$

(401) With the help of the above formulæ and numerical values, we can solve various questions of practical importance.

Thus, for example, we shall be able to determine the resistance on the level by making $\sin i = 0$, which gives us—

For a loaded waggon:

$$F = \frac{fr}{R}(P + P')$$

$$\frac{F}{P} = \frac{fr}{R}\left(1 + \frac{P'}{P}\right) = 0{\cdot}01 \times (1 + 0{\cdot}29)$$
$$= 0{\cdot}0129$$

and for an empty waggon:

$$F' = \frac{fr}{R}P'$$

$$\frac{F'}{P} = \frac{fr}{R} \times \frac{P'}{P} = 0{\cdot}01 \times 0{\cdot}29$$
$$= 0{\cdot}0029.$$

In other words, the resistance of a full waggon is about four times as great as that of an empty one.

Then, again, we can determine the *normal gradient*, as it may be called, of a mine railway upon which the full waggons travel only in one direction, namely, from the working places towards the shaft, and return empty.

In order that the labour of the men or horses engaged in the work of haulage may be properly utilized, it is necessary that the resistance be the same in both directions, for the full waggons in their descent, and for the empty ones in their ascent. The normal gradient is, therefore, at the same time *the slope of equal resistance.*

The resistance of a full waggon in descending is given by formula (2) of the preceding paragraph, and the resistance of the empty one going in the opposite direction by formula (1), in which we make $P = 0$.

We ought therefore to write:

$$\frac{fr}{R}P' + (P' + P'') \sin i = \frac{fr}{R}(P + P') - (P + P' + P'') \sin i,$$

from which we obtain:

$$\sin i = \frac{fr}{R} \frac{P}{P + 2(P' + P'')};$$

or, dividing both terms of the fraction by P, and at the same time introducing the numerical equivalents:

$$\sin i = 0\cdot01 \times \frac{1}{1+0\cdot80} = 0\cdot0055.$$

Thus the slope of equal resistance is about $\frac{1}{6}$ to $\frac{1}{5}$ in. per yard (5 to 6 millimetres per metre). This resistance, referred to the useful load, is:

$$\frac{F'}{P} = \frac{fr}{R}\left(1+\frac{P'}{P}\right) - \left(1+\frac{P'+P''}{P}\right)\sin i$$

$$= \frac{fr}{R}\left[1+\frac{P'}{P} - \left(1+\frac{P'+P''}{P}\right)\frac{1}{1+2\frac{P'+P'}{P}}\right]$$

$$= 0\cdot01\left(1+0\cdot29-\frac{1+0\cdot40}{1+0\cdot80}\right)$$

$$= 0\cdot01 \times \left(1\cdot29 - \frac{1\cdot40}{1\cdot80}\right)$$

$$= 0\cdot01\ (1\cdot29 - 0\cdot78) = 0\cdot0051$$

Again, we may find the *slope of equilibrium*, or that on which the full waggons are evenly balanced between a state of rest and a tendency to descend alone. For this purpose we have merely to make the general value:

$$F' = \frac{fr}{R}(P+P') - (P+P'+P'')\sin i,$$

equal to zero, and thence we get:

$$\sin i = \frac{fr}{R}\,\frac{P+P'}{P+P'+P''},$$

a value which is evidently higher than the preceding one, since the numerator of the second factor of the second term is larger, and its denominator smaller.

From this we obtain:

$$\sin i = 0\cdot01 \times \frac{1+\frac{P'}{P}}{1+\frac{P'+P''}{P}} = 0\cdot01 \times \frac{1\cdot29}{1\cdot40} = 0\cdot0092$$

In this case the resistance of the empty waggons in ascending is

$$F = \frac{fr}{R}P' + (P'+P'')\sin i;$$

and the ratio of this resistance to the useful load carried by the descending waggons is given by the formula

$$\frac{F}{P}=\frac{fr}{R}\frac{P'}{P}+\frac{P'+P''}{P}\frac{fr}{R}\frac{1+\frac{P'}{P}}{1+\frac{P'+P''}{P}}$$

$$=\frac{fr}{R}\left(\frac{P'}{P}+\frac{P'+P''}{P}\times\frac{1+\frac{P'}{P}}{1+\frac{P'+P''}{P}}\right)$$

$$=0{\cdot}01\times\left(0{\cdot}29+0{\cdot}40\times\frac{1{\cdot}29}{1{\cdot}40}\right)$$

$$=0{\cdot}01\times(0{\cdot}29+0{\cdot}37)=0{\cdot}0066.$$

We thus see that the resistance to ascent, which in the case of the *slope of equal resistance* is represented by the number 0·0051, is, on the other hand, represented by the number 0·0066 in the case of the *slope of equilibrium.*

This is an increase of 0·0015, or about 30 per cent.

However, the second plan (the employment of a slope of equilibrium) may in certain cases be at least as advantageous as one of equal resistance, if not with horses, at any rate, with putters (*hauliers, drawers, trammers*) when the incline is long, and the road sufficiently good to allow the waggons to traverse it without danger at a high speed.

The putters require only to push their waggon at the start, and then they jump on behind, and are carried down the remainder of the incline in a *very short time,* and almost without any exertion.

If we neglect this slight exertion and the time consumed in the operation, we see that *theoretically* they could pass over as much ground *in ascending alone,* as they would do in partly ascending and partly descending were the slope that of equal resistance. If then, we wished them to make the same amount of exertion in both cases, so that at the end of the day's work the amount of fatigue would be the same, they would have to ascend with lighter waggons, whose weight would be in the proportion of 0·0051 to 0.0066 as compared with those on the slope of equilibrium; but in the case under consideration they will push them twice as far

up the incline. Their useful effect will therefore be augmented in the proportion of 66 to 102, or about 50 per cent.

Such, then, is the *limit* of possible improvement that may be obtained by substituting the slope of equilibrium for that of equal resistance in the circumstances indicated; namely, where the *road is long,* and the railway in *very good order.*

This limit, which is not applicable unless the network of railways is simple, and the system of haulage well organized, allows a sufficiently wide margin to compensate for the time lost and the fatigue endured during the descent, as well as for any slight increase of gradient that might be desirable in order to augment the ease and rapidity of the descent.

(402) In what precedes we have supposed that the full waggons that have descended to the pits are brought back again empty up the same inclines towards the working places.

This may not always be the case, however, even if we neglect the carriage of timber and other materials, which generally correspond only to a small portion of the tonnage of the minerals that are carried downwards. For example, the method of working may require stuff for stowing, which is brought by the waggons as they return along the same railways to the working places.

It is plain that if the weight of the stowing were equal to that of the mineral, the road should be level, *theoretically,* and that, in general, a calculation similar to the preceding ones, would give the slope of equal resistance for *a given ratio* between the weight of the mineral and that of the stowing.

But it is often the case that the stowing is brought by a different set of waggons, and along other railways, than those on which the mineral is carried; and again, the waggons may be the same, but they may return to the workings by a different route.

In both cases the most favourable system of haulage is that which can be worked by means of falling gradients for the carriage of both the mineral and the stowing. We have already quoted the example of the Grand' Combe Mines (No. **337**), where in the principal workings the same waggons make a sort of circular journey, in which they leave the working places with coal, descend

towards the shaft, are raised to the surface, run to the places where they are emptied, and then to the quarries, where they are filled with rubbish; after this they enter the mine again at another point, and lastly, they descend towards, and return to, the same working places.

When the service of haulage is arranged in this way, the roads, being always traversed only in one direction, should, as far as local circumstances will permit, have *a slope in this direction almost equal* to the slope of equilibrium if the haulage is done by horses, and *fully equal* to it if men are employed for that purpose.

In the last case, the putters can transport on each journey loads of coal or mineral which are *theoretically indeterminate*, and are only limited by the conditions that the men must be able to start them or stop them on the incline without too great difficulty. One journey having been completed, they return up the incline *entirely unencumbered*, and take charge of a new load.

It is seen from what has been said, that in order to obtain the best results from mine railways, their longitudinal section should be regulated with great precision, as far as the gradients are concerned; the rolling stock should be studied with much care; and both the railway and the rolling stock should always be kept in a state of good repair. The smallest neglect in any of these particulars exercises an unfavourable influence, which increases in amount according as the normal resistance is represented by a smaller fraction of the useful load.

It thus happens that sometimes very variable results are obtained in circumstances which appear to be almost identical. For example, it is only necessary for the method of greasing to be a bad one, or the ratio of $\frac{r}{R}$ to be an unfavourable one, in order to double, perhaps, the term $f\frac{r}{R}$, and *reduce by one-half* the weight which a given motor can draw along the level.

(403) The following are some examples of results that can be obtained in practice:

1st. For great distances, 550 yards and upwards, with a good

gradient on which the putters descend at a high speed riding on the full waggons, and do no work except in bringing back the empty ones, the load may be 10 cwt. (500 kilos.), and the total distance traversed during the return journeys 10 miles (16,000 metres). The useful effect is represented by the figures $10 \times 10 = 100$ cwt. = 5 tons carried one mile (8 metric tons per kilometre).

2nd. For moderate distances of 200 to 300 yards, with a gradient approaching the slope of equal resistance, the corresponding figures may be 10 cwt. (500 kilog.) for the load, and 10 miles the total space traversed, that is 5 miles with the load, so that the useful result is 10 cwt. $\times 5 = 50$ cwt., or $2\frac{1}{2}$ tons trammed one mile (4 metric tons to one kilometre).

3rd. When children, or very young people, are employed in very low galleries, such as are to be found in several collieries in the department of the Nord, and in Belgium, the load must be reduced to about $4\frac{3}{4}$ cwt. (240 kilogrammes), and the distance traversed to $3\frac{3}{4}$ miles (6 kilometres), and the useful effect obtained under these circumstances is only $4\frac{3}{4} \times 3\frac{3}{4} = 17{\cdot}8$ cwt. carried one mile (1·44 metric tons carried 1 kilometre).

4th. With horses travelling long distances (1,000 yards and upwards) along small railways kept in very good repair, in high and well-ventilated galleries, the useful load of the train may amount to 8 tons (8,000 kilogrammes), and the distance traversed with it to $7\frac{1}{2}$ miles (12,000 kilometres). This gives us for a day's work of a horse $8 \times 7\frac{1}{2} = 60$ tons carried one mile (96 metric tons carried 1 kilometre).

5th. For shorter distances, and with the railways in an ordinary state of repair in mines in which *the temperature is high*, and *the ventilation more or less imperfect*, the load may be reduced to 5 tons (5,000 kilogrammes) or less, and the distance traversed to $6\frac{1}{4}$ miles (10 kilometres). In this way the figures would be reduced to $5 \times 6\frac{1}{4} = 31\frac{1}{4}$ tons transported 1 mile (50 metric tons carried 1 kilometre).

This result should still be considered very good, and is not always to be obtained in the circumstances that have been specified. It assumes that the horses are exclusively engaged in conveying trains all made up and ready for them, and not in the

work of distributing the waggons or forming the trains. If horses are employed upon this latter class of work we cannot increase the total distance traversed very much, and sometimes even have to reduce it a little, because of the numerous journeys and the consequent loss of time. It, therefore, follows that the daily amount of work will be reduced in the proportion of the load brought from a working place by a horse in one or two waggons, to the entire load of a train which it could have drawn. Its useful effect, instead of being 31 tons, might thus descend to 18, 12, or even less (30 to 20 metric tons or less per kilometre).

It should be observed besides that, everything else remaining the same, *heat* and *bad ventilation*, which reduce the useful daily effect of any animated motor whatever, act in a *much more marked* degree on horses than on men.

6th. Ponies are exclusively employed in the Newcastle mines in distributing the empty waggons to the working places, bringing back the loaded ones, and making up trains in the nearest main haulage way; moreover, the journeys are short, and the waggons are taken one at a time. The load is somewhere about 8 cwt. (400 kilogrammes) (see No. 389), and the distance only $5\frac{5}{8}$ miles (9 kilometres), although these little animals are both lively and active. The useful result is represented by the number $8 \times 5\frac{5}{8} = 45$ cwt., or $2\frac{1}{4}$ tons transported 1 mile (3·6 tons carried 1 kilometre).

If we suppose, as we have done previously, that the wages of a man are 2s. 6d. (3 francs) per day, and those of a boy 1s. 8d. (2 francs), and if we allow 5s. (6 francs) per day for a large horse, and 3s. 9d. (4·50 francs) for a pony, including the expense of the driver, the foregoing six examples considered above will give as the cost of one ton transported one mile:

	Per ton per mile.		Per metric ton per kilometre.
	s.	*d.*	francs
The first	0	6	0·375
The second	1	0	0·750
The third	1	$10\frac{1}{2}$	1·750
The fourth	0	1	0·0625
The fifth	0	1·9, or more	0·12, or more
The sixth	1	8	1·25

These amounts obviously vary between very wide limits, but they are all, even the very highest, much below the prices paid for carrying on the back or dragging sledges along the floor of the galleries.

The expediency of employing railways in mines is thus completely demonstrated, bearing out what we said originally; and the value of railways in mines increases with their extent. At the same time they furnish means by which underground workings can be developed so largely as to diminish the first cost of laying open a given area of mineral ground; they increase the individual output of each shaft, and thus they tend in general to reduce the cost of production, at least if the output *is not excessive;* for such a state of things causes loss of time in the work of the men, and introduces hindrances of one kind and another.

(404) It will be observed that the favourable results which we have pointed out are obtainable by the employment of *level* railways, or rather of railways with *gentle gradients* whose values we have calculated in Nos. 398 and 399. But it is not possible to reach all the working places by means of level railways in a seam which is not *almost exactly horizontal,* unless we were to drive an unreasonable number of galleries. Consequently, if the bed is more or less inclined, it is necessary to have certain sloping galleries for the purpose of connecting the various level headings with the main roadway. The slope of the inclined galleries which connect the level ones can be reduced by making them run in a *more or less diagonal direction,* instead of directly towards the rise. Theoretically, whatever may be the inclination of the seam or the difference of level to be overcome, the diagonal roads can be driven with as slight a gradient as may be desired, only it may happen that in this way the pillars would be cut at too acute angles, and that the road to a higher part of the workings near the winding shaft would be indefinitely lengthened.

In practice, we can employ inclines up to 1 in 5 when the rolling stock is light, by locking the wheels and converting the waggon into a sledge to a certain extent, according to the number of wheels prevented from turning.

Under these conditions, the work of putting is more laborious than on level roads, and 20 yards traversed on these half slopes are usually accounted as good as 30 yards on the level.

When the gradients are steeper the diagonal roads are replaced by self-acting inclines arranged in various ways. In inclines, as we shall see, the action of gravity is utilized for the purpose of drawing up the empty waggons, as well as for letting down the full ones; and they should be considered as the *natural complement* to level railways, serving, as they do, to reach the part of the field *towards the rise,* just as the railways serve to reach it *along the level.*

Lastly, it may happen, although this may be contrary to those principles of good management such as are generally taught, that part of the field at a lower level than the pit bottom has to be worked out to the dip, either if the seam is almost flat, or if part of it is lower than the bottom of the shaft, either from being thrown down by a fault, or from forming part of a sharp bend.

In this case the upward haulage has to be done by means of men or horses. But, since the resistance on the level is very slight (as we have seen in No. 401), a gradient of any importance increases it materially; for example, a gradient of 0·0129 is sufficient to *double it,* according to No. 401.

The usual motors, therefore, soon become insufficient, and it is necessary to have recourse to inclined planes; only, in this case, instead of being self-acting or worked by gravity, they are provided with some kind of fixed hauling engine. They are then called *engine-planes.*

(405) In the next chapter we shall further discuss the various arrangements that can be employed for the purpose of overcoming considerable differences of level by means of inclines to the dip or rise which require the application of special contrivances.

For the present, confining our attention solely to the question of transport along the level, we may say that, in addition to the methods already pointed out, namely, carrying on the back, dragging along the floor on sledges, and hauling on railways, another can be specified, namely, transport in boats on underground canals.

This method is not a new one. It was suggested by the engineer Brindley at the end of the last century, and was applied by him for the first time near Manchester, in the Worsley Mines, belonging to the Duke of Bridgewater.

A similar application, in a mine called Fuchs Grube, in Lower Silesia, is noticed in Héron de Villefosse's *La Richesse Minérale.* It was also employed in Upper Silesia, at the mines of Zabrze, in the mines of Clausthal, in those of Vialas, &c.

If we considered this means of transport only from the point of view of the useful effect of the motor, it would appear to be more advantageous than a railway, because the amount of the load may, so to say, be made almost indefinite, and the resistance to motion reduced *as much as may be desired* by diminishing the velocity. But this is only one side of the question; and since the cost of transport on a well-regulated railway is already *very low*, another means of transport, though perhaps realizing a more or less considerable *relative* economy, could only effect a small *absolute saving.*

Indeed, it is not often that navigation could be employed in mines. The distances are not usually sufficiently great to make the amount of saving per ton of importance, and the saving would generally be more than swallowed up by the inconveniences of loading and disloading, the cost of making and maintaining the navigable gallery, the difficulty of making it water-tight when working had to be carried on at a lower level, the necessity that would often arise of carrying the mineral from the canal to the bottom of a winding shaft, &c.

There would, therefore, generally have to be some special motive for applying this method. Thus, for example, at the Worsley Mines referred to above, the reasons for using it were the large quantities of coal that had to be carried, and the fact that the underground canals were in direct communication with an exterior one on which the mineral was transported to different parts of the country.

This system was gradually extended at Worsley, and led to the construction of three canals on different levels, altogether about 40 miles (64 kilometres) long. The intermediate canal alone came

out to the surface, and the two others were put in communication with it by means of pits in which the waggons with which the barges were loaded passed up and down.

The middle level is also at the same time an adit, in which an outward current can be made at pleasure by opening sluices, and in this way fleets of boats are carried outwards.

In the same way, at Clausthal, the navigable gallery serves as a means of conveying the minerals to the bottom of a single shaft, situated near the dressing floors at the surface; whereas, if the ore were drawn to the surface through the shafts near which it is broken, there would be an increase in the cost of winding in the first place, and a difficult and costly carriage above ground.

It will very rarely be found advantageous to adopt this system except in a few special cases. It is no doubt true that the useful effect of men on canals is considerable, and, in order to give an idea of its value, we shall quote the example of the Zabrze mines given by M. Ponson. In that case a hauler travels a distance of 2,078 yards (1,900 metres) with two boats containing together about 260 cubic feet or 6½ tons (74 hectolitres or 6,600 kilo grames), and makes two voyages per day.

The result would thus be $6\frac{1}{2} \times 2 \times 2{,}078 = 13{,}507$, or about 15⅓ tons conveyed one mile (25 metric tons carried 1 kilometre), and this would give a cost of about 2d. per ton per mile (0 fr. 12c. per metric ton per kilometre), which is the same as we arrived at in the fifth example given in No. 401. It is, however, certain that a better result could be obtained by augmenting the load, which is to some extent arbitrary, or by increasing the distance travelled over, which seems to be quite feasible. We think that the useful effect might thus be made double or more of that given above.

But even supposing this to be achieved, we should not have gained more than 1d. *per ton per mile* (0 fr. 0·6 c. per metric ton per kilometre), which is a very slight advantage for the comparatively small distances that mineral has to be conveyed in a mine, and would be more than counterbalanced if anything went wrong, or if any extra supervision were required on account of employing canals in the principal galleries, and ordinary haulage in the branches.

(406) By means of the figures given above an approximate idea can be formed of the cost of haulage in a mine for which the distances and the system adopted are known.

Suppose, for example, that we have a level seam in which the waggons are taken to the working places by hauliers, who travel a mean distance of say 220 yards (200 metres) to a main roadway, in which the waggons are made up into trains, and conveyed to the bottom of the shaft by horses over a distance of 1,100 yards (1,000 metres).

We shall suppose that there are fillers at the faces who are paid 2s. 6d. per day for loading 10 tons (10 metric tonne), or about	3d. per ton.
With a perfectly regulated slope of equal resistance, and a railway in good repair, we would have to apply the figure given in the second example (No. 403), say 1s. per ton per mile, for the hauliers. Let it be taken at 330 yards (300 metres), and we have 2¼d. per ton. We think that this figure should be increased to allow for the fact that the roadways near the faces are not always in good order for the last few yards, either as regards their gradients, or the state of repair in which they are kept. We shall allow 2½d. here	2½d. "
For the conveyance by horses we adopt the figures given in the fifth example of No. 403; viz., 1·9d. per ton per mile, or say	1¼d. "
Total . . .	6¾d. per ton.

This cost of 6¾d. does not include the expense either of greasing or keeping the rolling stock or the roadways in repair. These items may represent *a very variable sum* per ton per mile—for *the rolling stock*, according to the durability of its construction and the method of greasing; and for *the roadways*, according to the nature of the floor.

The following may perhaps be accepted as mean costs:

	Per ton per mile.	Per metric ton per kilometre.
Greasing	0·63d.	0fr. 04c.
Repairs of the waggons . . .	2·35d.	0fr. 15c.
Keeping the road in order . . .	3·14d.	0fr. 20c.
Total . . .	6·12d.	0fr. 39c.

CHAPTER XV.

APPLICATION OF MECHANICAL MEANS TO HAULAGE IN MINES.

In the previous chapter we have considered the various methods of applying the force of men and horses in haulage underground. It has been shown that, when the horizontal distances are very considerable, the employment of railways presents undoubted advantages over that of other kinds of carriage, such as carrying on the back, and haulage in barrows and sledges, in which the work is done on the natural floor of the galleries.

It has also been shown that the useful effect can be increased by improving the roads, either by keeping them in better order, or by reducing the gradients or the sharpness of the curves. Thus carriage on the back is applicable in the worst galleries, where the curves are abrupt, and the ups and downs have the most various inclinations. With railways, on the contrary, in order to have the normal resistance to traction represented by as small a fraction of the load as possible, it is necessary to keep the road in thorough repair, to make the curves gentle, and not allow the gradient to differ notably from the slope of equilibrium or that of equal resistance calculated in No. 401, for fear of greatly reducing the useful effect of men and horses.

Underground railways have to conform to the same code of rules, so to say, as those aboveground in regard to their gradients, and the state of repair in which the rolling stock and the road are kept, although they must differ from them essentially in plan or with reference to curves.

But if we take an elevation of the underground railways, it is very plain that they will not all be at the same level.

This is self-evident, if the seam is not horizontal, as in most cases it is not. But the same thing may happen, even if the bed lies horizontally, when it is divided by faults into various portions, situated at different levels; or again, when being horizontal, or nearly so, on a large scale, it presents in reality a series of undulations in opposite directions.

It may also occasionally be advisable to use a certain onsetting place for discharging the stuff obtained from workings lying below it.

Without entering into further details on the point, we must admit that, for several reasons, the various parts of a network of underground railways are not all at the same level, and that, even in the best managed mines, more or less considerable differences of level have to be passed over by means of rising or falling gradients, in order to reach the principal roads which communicate with the onsetting places.

For rising inclines it will be observed that, though the strain upon a level road amounts only to 129 ten-thousandths of the load (No. 401), an incline of 0·0129 doubles the resistance, one as slight as 0·129 increases it eleven times, and so on.

For falling inclines, when the slope of equilibrium is surpassed, it becomes necessary to hold back the waggon, or to skid a certain number of the wheels. If all four wheels are skidded, so as to turn the waggon into a kind of sledge, experience shows that it does not begin to slide on a less slope than one of about 1 in 6. But, then, in order to bring back the empty waggon, putting friction out of account, we have to raise the weight $P' + P''$ of the waggon, which requires an effort equal to $0{\cdot}16\ (P' + P'') = 0{\cdot}16 \times 0{\cdot}4\ P = 0{\cdot}064\ P$, or 143 pounds per ton (64 kilogrammes per metric ton) of useful effect; that is, at least five times the resistance on a level, and more than twelve times the resistance on the normal slope of equal resistance.

It is thus apparent that the agents which serve for the haulage on the normal slope soon become *insufficient* on these inclines except where they are tolerably short, the declivities moderate, and the waggons light.

When these conditions are not fulfilled, it becomes necessary to give up the ordinary agents, and have recourse to various mechanical combinations, such as are resorted to in the case of large railways at the surface, when it is desired to connect two points lying at very different levels, otherwise than by prolonging the line between them to a sufficient extent.

We shall speak successively of downward inclines in which gravity is the motive power; and of upward inclines, in which, on the contrary, gravity is the principal resistance to be overcome, be the motive power what it may; and lastly, we shall examine in a third paragraph how this other motive power established for hauling up inclines can be equally made to act on the level.

The first case corresponds to the employment of *self-acting inclines;* the second to the employment of inclines *with stationary engines;* the third and last, to *haulage on the level with stationary engines.*

§ 1. Self-acting inclined planes.

(410) The main object of inclined planes is to extend the field of operations towards the rise from the pit bottom, just as level railways extend it *along the strike.* A large number of different arrangements are employed, and it is important that we should make known the principles on which they are based, and the principal details concerning them.

1. *Details concerning the railways.* There are usually two distinct lines of rail along the whole length of the inclined plane. The full tub pulls up the empty one, and thus each line receives alternately the full one which descends, and the empty one which ascends.

Again we may obtain all the advantages of a double road, with a decided diminution in the width of the gallery, by laying down three rails at the upper end, four rails at the meeting place, and only two rails below the last point, as shown in figure 289. At *a* and *b* there are two switches, which are moved by the descending waggon after the ascending one has passed, and are thus brought into the proper position to guide the next empty waggon that ascends.

Lastly, there is sometimes only one line of rails along the whole self-acting incline, which is then said to be single-acting; the full waggon draws up a counterbalance, which, redescending in its turn, draws up an empty waggon.

With this arrangement the gallery need only be just large enough to take a single line of rails, and that is perhaps its principal advantage. In this case the counterbalance moves either on an ordinary tram in a parallel gallery; or on a very small tram on narrow rails, arranged so as to allow it to pass underneath the waggon; or, lastly, it may move in a *small* shaft or *staple*. The depth of the staple is regulated according to the weight of the counterbalance, in such a way that the work corresponding to one journey is the desired mean between the two absolute values, which correspond, one to the descent of the full waggon, the other to the ascent of the empty one.

(411) 2. *Details relating to the mechanism.* At the top of the incline there is machinery of some kind, to receive the rope, or ropes, by means of which the waggons are hauled.

This machinery may be a pulley with its axis either vertical, or perpendicular to the run of the incline; or it may be a drum fixed horizontally. In the first case there is a single rope, to the two ends of which the waggons which run on the plane are fastened; in the second case, there may be two distinct ropes, which are fixed to the drum independently, and coiled on it in opposite directions, or else one rope sufficiently long to allow of several turns being wound round the drum. When a single line of rails is employed with a balance-weight, the distance travelled by the balance need not necessarily be the same as that travelled by the full or empty waggons, provided the drum is made up of two distinct parts, with radii proportional to the distances traversed.

Lastly, a continuous or endless rope may be used, passing round a pulley both at its upper and lower ends. The one at the lower end is carried on a small carriage acted on by a weight, and in this way the tension on the rope can be regulated. One road then always receives the full waggons which follow one another at nearly equal distances apart, the other takes the empty ones.

No machinery of this kind is complete unless it is provided with a brake of sufficient power to stop it instantly at any point.

The brake is generally composed of a segment of wood fastened to a lever, surrounding part of the rim of a wooden or cast iron pulley, and produces on it an amount of friction proportional to the pressure put on the lever. A greater effect is obtained with an iron strap carrying several distinct brake-blocks, which distribute the pressure over a greater portion of the rim. The strap can be tightened or loosened by means of a system of levers fastened to its two extremities.

The brake may be arranged so that it is either *held against the rim* by a weight *when at rest*, or, on the contrary, is *loose when at rest*, and not tightened up until the brakesman moves it as he finds it necessary.

Of the two arrangements the first is preferable, since it offers a better guarantee against negligence on the part of the workman. Thus we lay down the principle that the machinery cannot be set in motion without the intervention of the brakesman, who starts it by lifting the handle; he moderates its speed by allowing the strap to press somewhat on the brake-wheel; and, lastly, he stops it altogether when he lets go the lever, and allows the counterpoise to exert its full force.

In order that the action of the brake may stop the waggons at the same time that it arrests the motion of the pulley or drum, there must be some kind of arrangement for preventing the rope from slipping.

With a drum this is a natural result, either because there are two distinct ropes, or because there are several turns of the rope round the barrel. Three or four turns will usually be more than enough to produce this effect; for it is well known that the resistance to slipping of a rope round a fixed drum increases very rapidly with the length of the arc which it embraces.

With a pulley having an ordinary groove a turn round only one circumference will generally be insufficient. It is then necessary to have a V-shaped groove; the rope then wedges itself into the the angle, with increasing tightness in proportion as the pressure which tends to produce slipping becomes greater. Another plan

is to use one of Fowler's clip-pulleys, which grasp the rope from the effect of the longitudinal strain; or, lastly, we may give the rope several turns round the pulley.

In order to avoid the wear and tear between the different coils as they roll off and on, the pulley is made with several grooves parallel to each other, and a second pulley is fixed close to it with one groove less than the first. The rope passes round both pulleys and rolls itself on and off, as regularly as if there were only an ordinary pulley, and the total length of rope for preventing the slipping is equal to the sum of the arcs receiving the rope on the two pulleys. Figure 291 is a geometrical representation of this very simple and very practical arrangement.

(**412**) 3. *Details relating to the manner of working inclines.* The mode of working differs according as the whole of the waggons to be let down are collected at the top of the incline, or are received at different intermediate levels. It varies also according to the degree of inclination of the plane, and whether it is single, or double-acting. In a very usual case where the inclination is slight, less, for example, than twenty-five or thirty degrees, and where the plane is double-acting, and receives the waggons only at the top, the putter or hauler on arriving at that point places his full waggon on the rails of the incline, and at the same time fastens it to the end of the rope. The brakesman waits attentively until he receives a signal from another hauler, who similarly places an empty waggon on the rails at the lower end, and fastens it to the other rope. As soon as he gets the signal he lifts the brake, the waggons glide away rapidly, and he regulates their speed by applying a gradually increasing pressure on the lever. This increasing pressure is necessary for the reason that if it were uniform from top to bottom the velocity of the waggons would be accelerated, inasmuch as, to the constant resistance offered by them and by the friction of the whole length of the rope, it is necessary to add the weight of the ascending part of the rope, which *goes on decreasing,* and this amount must be deducted from that of the descending part, which *goes on increasing.*

This tendency to acceleration may be counterbalanced to some

extent by increasing the inclination at the top of the plane, and decreasing it at the bottom; but this can rarely be effected without undertaking a considerable amount of dead work.

This plan is quite impracticable in the case of inclines with movable pulleys, which are removed from time to time to a higher level in proportion as the incline is lengthened. This is the usual arrangement when the faces are driven directly towards the rise. The inclination of the plane is then the same as that of the seam at every point, and one is not in a position to alter it.

Moreover, the method of making the plane steeper at the top and flatter at the bottom, is more conveniently employed at the surface than in mines.

When the inclined planes have only a slight gradient, it becomes possible to send off a large number of full waggons from the top and an equal number of empty ones from the bottom, at one time; and in this way, when they are very long, and the time occupied in traversing them is relatively much greater than that consumed between the journeys, the quantity that can be delivered by them is considerably augmented.

On the other hand, when the inclination of the plane is very pronounced, thirty degrees and over, as in edge seams, it is difficult to get the waggons to run on the rails alone, as they are apt to partly empty themselves during the journey. In that case *carriages* are most usually employed, which remain always attached to the two ends of the rope; they are constructed with a platform which remains horizontal, as they are running on the incline. At the two extremities of their course the platform is level with branch plates, or with the roads which receive the waggons, and these pass easily from the carriages on to the rails or inversely. Furthermore, they are held on the carriages during their transit by some kind of catch, which may be readily imagined.

(413) It is usually necessary that there should be a means of passing the waggons at the top of the incline on to either line of rails, according as one or other is free. In the case of inclines on which carriages are not employed, this may be effected by means of the system of roads shown in figure 292, which are established on the

level part at the top of the incline, or at an intermediate landing-place if there is more than one level. We see that, by this system, a waggon which arrives on one line of rails or the other, of the plane, can at pleasure be allowed to remain on the road by which it came, or be transferred to the other one, or be taken into one of the level-course galleries which intersect the inclined plane at this landing. The branchings and crossings are not constructed differently from those shown in figure 265, as A, B, and C.

Instead of having level crossings, it is often simpler to construct double entrance plates (figure 293); so that it is easy to pass from one road to the other, by guiding the waggon by hand, just as the switches served to do in figure 292.

These two systems of branches or entrance plates at the landing-places cannot well be employed unless the general inclination of the plane is such as to allow of the landing-places being made nearly level. This is essential for easy handling, especially when the waggons are somewhat heavy, without producing any sharp rises or drops on the inclined plane, as they cause jerks which tend to break the ropes.

When the slopes are considerable, a level landing-place may be made at pleasure at any given level, where it is desired to receive empty waggons or send away full ones. Movable rails are employed for this purpose, which can be put in place when it is desired to continue the plane further, but can be raised temporarily when it is desired to form a landing-place. (See fig. 294.)

Lastly, if the slope is very great, and requires the employment of carriages, in the manner pointed out in the preceding paragraph, the most simple way is to put up a kind of bridge or movable platform, turning on a horizontal axis. Its usual position is vertical, but it can be laid down across either of the roads of the inclined plane, in such a way that when it is in position it will be on the same level as the rails of the adjoining level-course galleries. If, for example, the empty waggon that is being taken up the incline is on the right-hand carriage, the bridge or platform is turned down across the space above the rails on the left-hand side, in such a manner that the empty waggon is thereby put into connection with the

left-hand level-course gallery, just as it is already directly with tl one on the right-hand.

(**414**) We have said that the waggons can be taken on and c the incline, sometimes at its upper end, and sometimes at inte mediate levels, as the case may be.

The first is the most simple case. If the incline is doubl acting, the length of the ropes is regulated once for all, in such way that when one end is at the top, the other is at the bottor and the manner of working is then what we have pointed out abov (No. 412.) A single incline of this kind, if well managed, is abl to let down a very large number of waggons during a shift. If tl road is in good order, a mean velocity of 6 ft. (2 metres) and mor per second may be attained; the work at the top and bottom nee not occupy more than a few seconds if plenty of waggons a at hand; and lastly, if the incline is very long, 160 yards (15 metres) or more, for example, so that the time occupied at tl top and bottom constitutes a *small* fraction only of the tim occupied in running, it will be found advantageous to send sever waggons at a time, thereby increasing the amount of stuff passin over it, and rendering it, as it were, independent of its length.

For large outputs, it may again be more convenient to substitut an endless rope or chain, having a continuous movement, for tl two separate ropes or the rope with two ends. The full waggor are attached to the descending side of the rope, and the empty one to the ascending side, in regular succession, as they present them selves at the top and bottom landing-places.

This system permits of very large quantities being handled; requires strong brakes, and attentive brakesmen, as well as activ men for hooking the waggons off and on, without stopping tl motion of the rope.

(**415**) When it is necessary to work at several intermediate leve as well as at the top of the incline, as, for example, when a inclined plane taking the place of several diagonal roads is servin a system of level-course working places, onsetting may be don either *successively* or *simultaneously* at different levels.

In the first case, when the work at any single level is finished, we can go to another one by altering the length of the ropes. This can be done by having two distinct drums on the same shaft, one fixed to the shaft, the other movable on it at pleasure. It can then be arranged, that when a full waggon arrives at the bottom of the plane, the empty one on the other rope just reaches the desired intermediate landing-place, and not the top of the incline. The same object can be attained by having pieces of rope of the required lengths, which are added to or taken away from the incline rope, for the rope must be longer when one of the lower levels has to be served.

When the onsetting operations ought to go on *simultaneously* at different levels, which is generally the best arrangement for keeping the working places clear of coal, one of two systems may be employed.

Firstly, an endless rope may be used, with one side for letting down the full waggons, the other for bringing up the empties. When a hauler presents himself at any intermediate landing, he signals for the rope to be stopped, and attaches his waggon to the proper rope by means of a small piece of chain terminating in a shackle, which he tightens up with a screw, and then places his waggon on the plane. The rope is again put in motion, and the same hauler gives the signal for it to be stopped when an empty waggon arrives opposite the landing-place.

In order to facilitate these operations at the intermediate landing-places, the rope is made *to pass over the tops of* the waggons that are attached to it. It is, therefore, easy to cross from one side to the other, or to fasten on a waggon without being inconvenienced by the rope, which has merely to be raised a little with the hand.

The second system consists in having a single-acting incline, with a *counterbalance.* Inasmuch as the counterbalance does not arrive at the end of its course until the empty waggon arrives at the top of the incline, it is evident that it is always in position to let down a full waggon from any part of the plane to which it has brought an empty one.

The mode of operating at this landing-place is to stop the empty

waggon as it arrives, by signalling to the brakesman, then to detach the empty and attach the full waggon, and finally to give another signal to let down the full one.

This arrangement is perfectly applicable when the distances between the various landings are not very great, when the time occupied in running is short, and when it is not inconvenient to have *two operations in succession* for the purpose of replacing an empty waggon by the full one which arrives at any given landing-place. This arrangement is also applicable either *with* or *without* a carriage.

(416) 4. *Various details.* Besides the general details mentioned above concerning the lines of rails, the brakes, and the operation of onsetting, there are others of a secondary importance which also deserve to be mentioned.

Thus, for example, it is necessary to hinder the ropes from dragging on the ground, so as to diminish both the resistance caused by their friction, and the wear and tear.

For this reason the rope is made to pass over rollers, which ought to be sufficiently high above the road, and close to each other, to prevent the rope between them from touching the ground. These rollers ought to have a large enough diameter in proportion to the size of their axles, and the axles themselves should be kept greased, so as to ensure that they will always run round. These things are not always attended to. It is too often the case that the rollers do not turn, and that the ropes wear away in consequence of the friction caused by their rubbing as they pass over so many fixed points.

With a rope of considerable length, the total amount of pressure on these fixed points is practically equal to the component of the weight of the rope at right angles to the plane, and the friction resulting from this cannot be neglected.

Arrangements may be made for preventing the accidents and disorders caused by the breakage of either the ascending or descending rope.

In the case of the ascending rope, the simplest plan is to fix a kind of fork with two long branches behind the waggon, which

trail on the ground and at once stop it if it tends to run backwards. The stoppage is effectual; for as the waggon has acquired a certain amount of velocity in going upwards, it has not time to acquire any velocity downwards before the catch comes into operation.

It is different with the descending waggon, because *after the rope breaks* its velocity is the same as *before.*

In the last case, then, it is necessary that the safety apparatus should come into action at the very instant the rope breaks. In order to effect this, the rod with prongs may be kept up by some kind of easily-conceived system of jointed rods while there is any tension on the rope; and when the rope breaks, its points are instantly dug into the ground by the operation of a balance-weight, which comes into play when the tension disappears.

However, it is not usually the descending rope that breaks on a self-acting incline; and in case the ascending one breaks, the rod with prongs stops the corresponding waggon from running back, and the application of the brake holds the other one. It is usually sufficient therefore to confine the application of a safety apparatus to the ascending waggon. Its employment is, however, far from being general, and more often the risk of a breakage is run, with its accompanying wreck, and more or less complete smash of the waggons. Care must then be taken to watch the ropes attentively, and change them in time, in the same way as is done with winding-ropes.

Lastly, we will notice an arrangement proposed by M. Taza-Vilain for inclined planes, with a carriage and a counterbalance on wheels, designed to work a series of level-course working places in steep measures.

It is well known that, in order to shorten the length of the ordinary roads to be kept in repair, care is taken to move the self-acting inclines nearer to the faces from time to time. They may thus be placed successively at points where the inclination is very variable. The carriage designed by M. Taza-Vilain is constructed so that the platform is always in an approximately horizontal position; the angle which it makes with the framework can be varied, as it is fastened by a hinge and bolts. (Fig. 295.)

the saving effected in the transport and wear and tear of the roads will largely repay the original outlay.

We do not propose to enter into any of the details regarding these balance-pits, since they are merely reproductions on a small scale, and in a simple form, of the arrangements which we shall describe further on when we come to speak of winding shafts.

We shall here simply remark that these balance-pits are capable of rendering very useful services, and that they are not as generally employed as they ought to be.

§ 2. Haulage from the dip with stationary engines.

(419) An inclined plane going towards the dip is intended to reach that part of the field of operations lying below the level of the pit bottom, just in the same way as self-acting inclines extend the workings towards the rise, and ordinary railways along the level.

In a general way, the railways on an incline of this kind are arranged exactly like those of a self-acting incline, and various modifications may be adopted, like those mentioned in No. 410. The waggons again are handled in the same way, save that here the full waggon is drawn up, and the empty one let down.

It is a different matter when we come to deal with *the means* by which the work is performed. It is always necessary to have machinery at the top for working the ropes to which the waggons are attached. It must also be provided with a good brake, capable of preventing any premature movement, or stopping any acquired motion, at pleasure. Instead, however, of being able to utilize gravity as a motive power for the purpose of drawing up the full waggon, it is necessary in this case to derive power from some prime mover capable of overcoming the resistance offered by the weight of the full waggon, minus the weight of the empty one.

The motive power may, in the first place, be animated, such as that of men or horses.

Men may work a windlass, fixed at the top of the incline, by means of handles attached either directly to the barrel, if the

apparatus is *simple*, or geared with it, if the apparatus is *compound.*

Horses will drive the drum of a gin.

There is nothing new in either of these systems beyond what has been already described in the *Cours des Machines.* (Nos. 39 *et seq.*)

It is there stated in regard to these two machines, which are almost the only ones employed in mines in connection with animated motors, that the useful effect obtained under favourable conditions is 1,012,640 foot-pounds (140,000 kilogrammetres) for men, and 7,233,140 foot-pounds (1,000,000 kilogrammetres) for horses. These figures, which represent the amount of work done in raising weights *vertically*, may be taken as approximately correct in the case of all inclines that are so steep as to make it possible to neglect the rolling friction, as being a very small quantity compared with the weight to be raised in the waggons against the force of gravity.

The above figures are equivalent to the statement that a man in the course of a day's work will raise 1 statute ton to the height of 452 feet (1 metric ton, 140 metres), whilst a horse will raise it to a height of 3,229 feet (1 metric ton, 1,000 metres).

This weight will be *net* when the incline is double-acting, for then the weight of one waggon will balance that of the other.

It is obvious that it is a very different matter when the incline is single-acting, the full waggon being drawn up by the motor, and the empty one let down by the brake. In this case a dead weight equal to 40 per cent. will be raised uselessly (No. 400), and the useful effect of the motor will be reduced in the same ratio.

This loss may be avoided, however, by employing a counterbalance in the same way as on a self-acting incline. The counterbalance descends while the full waggon ascends, and it is raised while the empty one is being let down.

Theoretically speaking, and neglecting all the passive resistances, the counterpoise will balance the empty waggon, and will consequently reduce the resistance by an equal amount while the full waggon is ascending, so that only the useful load has to be raised.

(420) The above figures, 1,012,640 and 7,233,140 (140,000 and 1,000,000), show that a dip incline, provided with a windlass, or even with a gin, is incapable of delivering much coal, and could not, like a well-organized self-acting incline, serve an extensive district, or overcome a great difference of level.

Suppose, for instance, taking simple numbers, that the difference of level is 46 feet (14 metres), and that it is required to raise 100 tons (say 100 metric tons) per shift, the corresponding work will be

$$46 \times 100 \times 2{,}240 = 10{,}304{,}000 \text{ foot-pounds}$$
$$(14 \times 100 \times 1{,}000 = 1{,}400{,}000 \text{ kilogrammetres}).$$

This will require ten men at the windlass, which cannot easily be managed, or two horses at the gin. Thus even with this small depth the windlass becomes disadvantageous and inconvenient, and it would already be better to employ a horse gin.

Suppose the difference of level to be 138 feet (42 metres), and the weight 300 tons (300 metric tons), so that the work is about nine times as great as before; it would require 90 men, a number which puts the windlass quite out of the question, or more than 12 horses, which could not be employed on one gin during a shift without great difficulty.

Thus, without saying anything about the cost, which would be enormous, it would be decidedly necessary to give up *animated motors* for drawing a large output up an incline.

What other motor can supply their places?

We can evidently have recourse to one of the two remaining motors used in the arts; viz., firstly, a natural fall of water which is at hand at the surface, or can be created by driving an adit level; or, secondly, steam power.

Again, we may have recourse to an *artificial* motive power, as it were *second-hand*, which can be arranged either by pumping up water from the bottom of the mine after it has acted upon a water-engine at the top of the incline, or by compressing air and conveying it to an engine in which it acts exactly like steam. The choice to be made between these various motors has been referred to in general terms in the *Cours des Machines*. (Nos. 309–312, and 392).

It will require to be reconsidered here with some modifications due to this particular application.

We may imagine a hydraulic apparatus placed at the top of the incline, such as a small rotatory water-pressure engine. The water, which is conveyed to it in pipes, can be collected in a reservoir, situated either at the surface or in the workings, and after it has done its work, it may be allowed to run away of its own accord, or it may be conducted in a pipe to the adit level, which may be higher than the top of the incline.

If there does not happen to be an adit, the water will flow or be conducted to the sump of the pumping shaft, whence it will be raised up again to the reservoir by the ordinary pumps.

These arrangements are very rational, and in this way the necessary power is easily obtainable, either naturally, or by giving the pumps the small additional power required to enable them to raise the extra quantity of water, which redescends to work the hydraulic machine placed at the top of the engine-dip.

A very suitable machine is a rotatory water-pressure engine, with two double-acting cylinders, working a crank-shaft, or three single-acting ones, with reversing gear, like that of a steam-engine. A machine of this kind, working at a very high pressure, occupies little space, and is easily put in place and worked.

This system is very satisfactory in principle. The practical difficulties which interfere with its application are due to the large diameter which it is necessary to give the pipes (*Cours des Machines*, No. 396), and above all to the enormous pressure, amounting sometimes to as much as a height of several hundred yards, to which the water is subjected in the lower parts of the column and in the engine.

(**421**) For the last thirty years it has been customary in England to place special steam-engines underground for haulage purposes, both on dip-inclines and on level roads.

The employment of these machines, which are very largely used in England at the present day, is not without many inconveniences. If their boilers are underground as well, their position is not by any means a matter of indifference; for it is a *sine quâ non* that

the products of combustion be conveyed to the upcast shaft as directly as possible, without finding their way into the galleries traversed by the workmen. On the other hand, although great care may be taken to supply the fires with fresh air only, still they are far from being free from danger in fiery mines. It may happen that, in consequence of culpable negligence, an atmosphere charged with inflammable gas is allowed to come in contact with them, or it may be that the air-stoppings having been destroyed by *a first explosion*, a current of air which is still explosive is drawn towards them, and, being thus ignited, produces *a second one.*

These risks are so great, in our opinion, that boiler fires should not be permitted in fiery mines, except where ventilating furnaces can be used. The two kinds of fires ought to be in the same neighbourhood, and they should be subject to the same regulations; otherwise the boilers should be most certainly placed at the surface, and then the steam can be conveyed to the engines underground in pipes that are well jacketed in a non-conducting envelope, so as to preserve them as much as possible from loss of temperature, and the consequent condensation of water and fall of pressure.

Whether the boilers are placed at the surface or near the ventilating furnace, they are usually far from the point where it is most suitable to place the engines which they are intended to work. It is therefore necessary either to put up with the cooling and condensation referred to above, as well as the inconvenience of the leakages from the engine, or to remove the engine itself from its natural position and bring it nearer the boilers, either at the bottom of the shaft, or even at the surface. It is then connected with the point where its power is to be applied by a system of endless ropes.

All these combinations consequently have their own inconveniences.

It would appear, therefore, that where it is necessary to put up machines in several parts of a mine, either for drawing from the dip, or for any other purpose, the best system would be the following:

To erect a steam-engine at the surface close to its own boilers,

working an air compressor capable of supplying enough compressed air to work the various engines underground, even if they were all required to be in use at the same time, either for drawing up coal from the dip, which is the special case now before us, or for any other purpose, such as working coal-cutting or drilling machines. (See No. 154.)

In this way we avoid the dangers and inconveniences inherent to having fires in the workings underground. We also escape from the difficulties caused by the large dimensions of the pipes, and the heavy pressures to which they would be subjected if we employed water; from the trouble of the heat and condensation that would accompany the use of steam; from the difficulties of transmitting power to long distances by means of ropes in more or less sinuous galleries already sufficiently encumbered; and, lastly, we improve the temperature and ventilation instead of deteriorating them.

On the other hand *we lose motive power;* and it cannot well be otherwise, since we interpose a more complex system of intermediate agents by adding an air-compressing machine between the steam-engine and the rope to which the waggons are attached.

If we suppose that the steam-engine when acting directly on the rope gave a useful effect *in raising mineral* of 80 per cent., and that in working the less simple system of compressing air with a piston it gave 50 per cent. in *compressed and cooled air,* then the useful effect of the complex apparatus would be $0{\cdot}80 \times 0{\cdot}5 = 0{\cdot}40$.

It follows, then, that a steam-engine intended to work a dip-incline by means of compressed air would require to be twice as powerful as if it acted directly on the rope.

But this advantage cannot be obtained unless the engine is placed immediately *at the top of the incline.* It would evidently decrease rapidly as soon as the distance from the work, and the number of parts to be put in motion, began to increase; for it becomes necessary to take into account the passive resistances due to the series of ropes employed in transmitting the power, whilst the pipes that conduct compressed air can do so for a very great distance without sensible loss, provided they are large enough. (See *Cours des Machines,* No. 354.)

(422) After these remarks we shall assume in general, save in exceptional cases modified by local conditions, that *all engines working in the interior of a mine at a great distance from the shaft are driven by compressed air, produced at the surface by another machine worked by a steam-engine.*

However, numerous instances may be found of other systems.

Thus, for example, boilers may be placed *at the surface,* and send their steam down to an engine, *near the bottom of the upcast shaft,* by means of pipes, which are well protected against cooling. This plan is a perfectly acceptable solution of the problem, inasmuch as it economizes the motive power on the one hand, and presents nothing objectionable in the form of possible danger in the presence of gas, or inconveniences to the ventilation of the galleries.

Under such conditions this system might indeed be the best; but it is by no means the same thing when the power has to be applied at a distance from the shaft, or distributed at a number of separate points. In a case of this kind, which will probably be more and more common in future, the system of compressed air is the one which appears to merit the preference, as giving the most practical means of transporting and distributing the power to any given point.

In recapitulation, we may say that an incline to the dip can be constructed, as regards the arrangement of the lines of rails, like a double self-acting incline, or a single one with a counterbalance, with or without a carriage; that, like a self-acting incline, it should have machinery at its upper end provided with a complete brake; but that this machinery, instead of being set in motion by the force of gravity acting on the masses which traverse the incline, will be a windlass in the case of inclines of little importance, a horse-gin for those of moderate importance; and a regular engine, worked by compressed air, for those that are very important, either in respect of their depth or their large output, and are situated far away from the shaft.

We shall add that, in the last case, the ropes will be either wound upon or unwound from the drums directly, or they will pass over pulleys supported on a framework at the top of the incline.

We must here repeat the remarks which we made in speaking of self-acting inclines, regarding the means to be adopted for enabling a large amount of traffic to be carried on. It is necessary, above all, to erect an engine of sufficient power to raise the required number of waggons, taking into account the slope of the plane, and the velocity at which they will have to be drawn.

But, in general, the output will increase in proportion as the number of operations diminishes, because the time lost between the operations will become of less importance. For this reason it will be well to have an ordinary incline with two roads and two ropes, with which a certain number of waggons are raised at a time, or a single endless rope or chain kept in constant motion, and drawing up a series of full waggons to the top landing-place on its ascending side, while a series of empty ones are being let down on the other.

The last system is capable of giving a large output if it is kept properly supplied.

Besides, by the aid of a simple contrivance, it can be made available for serving, not only the bottom of the incline, but also any number of intermediate levels that may be desired. It is only necessary to have movable drawbridges (fig. 302) at each level, which can be depressed at pleasure so as to receive the full waggon, for the purpose of attaching it to the ascending branch of the chain, or for receiving the empty waggon brought by the descending branch; and as soon as a waggon is taken off or on, the drawbridge is lifted up again at once.

None but attentive and practised workmen should be employed for this work, as we have already pointed out when speaking of self-acting inclines with endless chains.

The remarks we have already made concerning self-acting inclines (Nos. 410 to 417), and the description we shall give later on of winding operations, will relieve us from furnishing further details in this place. In principle, the *mode of haulage* from a dip working does not differ in any way from the operation of *winding* from an inclined shaft which terminates at the surface.

It may not differ even from the ordinary operation of winding, if the dip incline is replaced by a blind pit, similar to those de-

scribed in No. 418, except that it would be used for *raising* instead of *lowering* minerals.

§ 3. Haulage along the level by means of stationary engines.

(**423**) The adoption of machinery in mines for the purpose of hauling from dip-workings has naturally led engineers to attempt to extract further profit from the same arrangements, by extending their action to level, or rather, undulating roads, where the quantity of stuff to be transported is considerable, the distance long, and the ground sufficiently firm to permit of strong and durable ways being laid down.

Indeed, all these conditions are necessary, in the first place, to justify the establishment of rope-haulage in a mine, and in the second place to render it possible; and when once the machinery has been put up, the output can be increased, and the field of operations extended further from the shaft.

It is especially in the extensive collieries of the middle and north of England, where the character of the seams is exceptionally favourable, that mechanical haulage is common, and is constantly tending to become more so. On the contrary, there are no examples on the Continent, or at most only a few; in France, for instance, few localities could be named where the application of this kind of haulage would be really advisable. It is necessary, however, to be acquainted at least with the principle and the essential details of the various arrangements that are in use.

They are described in an important memoir that was published in 1869, under the auspices of the "North of England Institute of Mining and Mechanical Engineers," with the title of *Report on the Haulage of Coal.* This report, which was drawn up by several eminent English engineers, was translated into French by MM. A. Briart and J. Weiler, engineers at the Mariemont mines (Belgium), and the translation was published at Mons in 1871.

This work contains a large number of very interesting details concerning the various systems in use in different colliery districts.

These various systems are the same in principle as haulage from dip workings, with this difference, that the empty waggons do not return towards the points where they are loaded by the action of gravity, but require the employment of a motive power quite as much as the full waggons which are being drawn towards the shaft.

In principle this may be done in two ways:

In the first place, we may have *two distinct ropes*, one attached to the front end, the other to the back end, of the train. They are drawn alternately, and first bring the full waggons towards the shafts, and then take the empty ones towards the working places.

While the end of one of the ropes is pulling the train, the end of the other is being drawn by the force of the first one.

In the second place, we may have an endless rope or chain, and apply the various arrangements to it that are required when it is used on a dip incline.

(424) We shall speak in the first place of the employment of two ropes, which is known in England under the name of the *tail rope system*. This expression refers to the simultaneous employment of two ropes—the *rope in front*, and the *rope behind*—attached to the same train in whatever direction it may be intended to move.

It might also be called the system of *haulage with two ropes*.

This is the system which prevails in the Newcastle basin, to which it is, as we shall see, more particularly suitable.

It consists in general in having a steam-engine *erected underground* somewhere near the winding-shaft, while the boilers are either *at the surface*, or near the *ventilating furnace*. The plan of having the engine at the surface, and near to the boilers that supply it, is seldom employed, and cannot be recommended. The engine, whatever be its type, works two drums, either of which can be thrown out of gear at pleasure, and both have good brakes. One of them carries the *front rope*, which is attached to the front end of the train at that point of the mine where the haulage by the engine begins; the other carries the *tail rope*, which on leaving its drum passes round a return pulley situated beyond the point at

which the train is formed, and is then brought back and attached to the rear end.

On starting the engine, after having thrown the drum of the hauling rope into gear, and the other out of gear, and pressing its brake gently, the train starts towards the shaft, drawn by the front rope, and dragging the tail rope after it, the tension of the latter being regulated by the brake of its drum. On arriving at the shaft, the full waggons are replaced by empty ones. The drum carrying the front rope is then thrown out of gear, while its brake is put on slightly; the tail rope drum, on the contrary, is thrown into gear, and then the engine is ready to draw the empty waggons back to the point where the full ones came from. There the empty ones are detached, and taken to the working places to be filled, while a new train of full ones is prepared.

Such is the manner in which the operations are performed. It is obvious that each engine can work four drums quite as well as two, and that there may, consequently, be two principal engine-planes in the same mine. There may, besides, be one or several branches in each of these planes, so that we can have as many distinct points as we like where trains are formed, each serving a more or less extensive district in which the rest of the haulage is done by ordinary methods; that is, either by men or horses, according to circumstances.

Figure 303 is a diagram showing how an engine may be arranged for tail rope haulage.

The engine is made with two cylinders, and drives two drums—one for the front rope, the other for the tail rope.

Each drum is provided with a brake, not shown in the figure. Each of them can be put into or out of gear by means of a movable plummer block, situated on the same side as the gearing. The plummer block is moved by means of a small lever or screw-wheel. (Fig. 304.)

The ropes pass from the drums on to pulleys, which bring them into the proper lines—the front rope into the axis of the engine-plane, the tail rope into one of the upper angles of the gallery, along which it is guided to the return pulley, from which it comes

back towards the front rope. This arrangement is shown by the diagram. (Fig. 305.)

Figure 306 represents the arrangements that should be employed at one of the branches. It is necessary, in the first place, that the branch and the straight road should be connected together by a curve with a tolerably large radius (1 chain at least); and, in the case of a branch at right angles, the angle of the pillar must therefore be well cut away (see No. 398), or else the curve can be made in a special gallery driven on purpose in the solid coal.

The ropes of the branch can be put into connection with those of the straight road, either when the empty train arrives at that point (fig. 306 A or 306 B), or when it is still at the bottom of the shaft. (Fig. 306 C.)

In the first figure, the rope of the branch takes the place of the piece in the continuation of the straight road.

In the second, the tail rope of the mainway being detached from the train at m, is drawn to m' by the engine, and there attached to the tail rope of the branch.

In the third figure, it is supposed that when the train is standing at the pit the two principal ropes present points of attachment just opposite the ends of the ropes of each branch. With this system there is a saving of time, because the ropes can be fastened on while the train is in course of formation, without requiring it to be stopped anew when it arrives at the entrance to the branch. It is more particularly suitable also when there are a large number of branches to be served.

Besides branches there may be *stations* at various points on a continuous plane, where trains are left or picked up.

The arrangement applicable in such a case is shown in figure 307.

At the side of the main line of rails there is a siding forming a *cul-de-sac* towards its lower end, and joined to the main line at its middle point and higher end.

The full waggons, brought by the putters or haulers from the district to which the gallery A serves as an outlet, are placed on the part B of the siding, where they are joined together to form a train.

When the empty waggons arrive at C the ropes are detached, and they are guided by hand into the siding at D, where they are at the service of the haulers. The ropes are then attached to the full train, and the proper signal being given, the engine starts in the contrary direction.

Such are the general arrangements that may be made to supply the various wants of haulage.

We add as a practical detail the arrangements employed for guiding the movements both of the waggons and ropes by means of rollers and guide rails. (See fig. 308.)

We also represent (fig. 309) the system that can be adopted for rendering the operations of hooking on and hooking off the trains at the branches and stations both prompt and easy.

We shall return again to both of the above figures in describing the plates.

The preceding details include all that is essential for understanding the tail rope system. It will be remarked that one complete journey, including the going and returning of a train, together with all the losses of time, must be made at high velocity in order that it may not occupy more time than is necessary for winding the 30, 40, and possibly 60 waggons, of which a train is usually made up. This great velocity necessitates the employment of considerable power, and it is stated that some hauling engines work up to as much as 150 horse power.

The speed is, besides, not the only object for which so much power is employed. It is obviously necessary to provide sufficient power for that instant when the train is at the most unfavourable point on the road, that is to say, on the steepest rise; and the result of there being no connection between two consecutive journeys is that the force generated by the previous train of empty waggons in descending the same part of the road is not stored up, and kept in reserve for the next following upward train. In short, the engine plane operates like a single self-acting incline, or a dip incline without a counterbalance.

The velocity, which is often as much as four or five yards per second, also makes it necessary to maintain the roads in a good state of repair, so as to avoid the danger of running off the rails. From

this point of view it seems desirable that each train should be accompanied by a guard or rider, who can make signals to the engineman, and replace on the rails any waggons that may have run off.

After what has been said in the preceding paragraphs, it will be seen that this system is most applicable in very extensive mines, where a large number of branches can be made, and where the seam lies so favourably that the main roadways can be constructed with upward or downward slopes, varying but slightly in amount, and can always be kept in a state of good repair.

Tail rope haulage is dear as regards first cost, and expensive in repairs, because of the power required for the engines, the great consumption of fuel, and the rapid wear both of ropes, accessory pulleys, rollers, &c., which are necessary for guiding each rope properly. On the other hand, it has the advantage of requiring only one line of rails in the galleries.

(**425**) The *endless rope*, or rather *chain*, such as is used principally in Lancashire, is little known at Newcastle. It is essentially different from the preceding system; and, in fact, it has several properties which are, as it were, the reverse.

In the first place it requires two lines of rails.

It entirely precludes the use of curves unless they are of very great radius, every curve in the least degree sharp demanding a special arrangement, and the presence of a workman.

The system consists in having a steam-engine of any type driving a pulley carrying an endless chain. The two branches of this chain pass along the centres of the two lines of rail, and round a return pulley at the far end of the double road.

Figures 310 and 311 give two examples of the manner in which one or two driving pulleys can be actuated by means of a system of bevelled wheels driven by a steam-engine.

In the interval between the driving pulley and the return pulley the chain does not rub on the floor, but is carried up by the full tubs on one of the roads, and by the empty ones on the other, the distance between every two, and the speed, being regulated according to the quantity of coal to be carried. The speed

is usually somewhere between 1 ft. 8 in. ($0^m.50$), and 5 ft. ($1^m.50$) per second; and the interval between the tubs from 10 to 30 yards (10 to 30 metres). In this way as many as eight or nine waggons a minute can be delivered, according to requirements, or more than the best winding engines are capable of drawing. In this respect this system has an advantage over the preceding one.

It is also superior, and in a more striking degree, as regards the amount of power required to drive it; for the regular distribution of both full and empty waggons along the whole length of the chain establishes, in the first place, a complete balance as regards the dead weight of these waggons; and, in the second place, if we take a distance travelled equal to the space between two waggons, the amount of work to be expended by the motor will be merely that of raising the load of one waggon from the point of departure to the point of arrival. From this consideration it will be seen, that the power required may become zero, or even negative; that is to say, that *it would be necessary to make use of a brake instead of a motive power* if the point of arrival were sufficiently far below the point of departure, whatever might be the profile along the intervening space.

It ought to be remarked that, in calculating the amount of friction, not only the dead weight of all the waggons, full and empty, must be reckoned, but also the total weight of the chain which rests upon them.

This property of the system, that the *principal resistance* is constant, and depends only on the difference of level of the extreme points, renders its application advisable in a district where the nature of the gradients is less regular than at Newcastle; it permits us easily to traverse a line presenting a series of considerable undulations. It will also be remarked that this property is not of less interest at the surface than underground, when a country is very irregular, and it is desired to convey the products of a mine to considerable distances from the shaft, or, on the contrary, to concentrate the products of several mines at one point.

This is done every day in Lancashire, and the system is being introduced also on the Continent; for example, the products of a

mine are carried to a canal, a railway, or to a place where they are consumed; or, again, the products of several mines are brought together to the same point for the purpose of being screened, washed, coked, &c.

The endless chain system is destined to render very great services in the future. It may be somewhat expensive to establish, in consequence of the cost of the chain, the necessity for having two roads, and the large amount of rolling stock constantly on the lines when they are very long; but, to make up for these disadvantages, it reduces the cost for power, the expense of repairs, and it admits of the *gradients* being made just as *steep* as those of an ordinary road. On the other hand, when we come to deal with *curves* its use becomes restricted; in fact, as soon as there is any departure from the straight line, unless the curves are of great radius, there is the risk of the chain being drawn off the tubs, on which it merely rests without being attached to them, in consequence of its constant tendency to be drawn out straight.

Moreover, the economy in labour, which is an essential characteristic of the system on long, almost straight lines, is no longer realized when there are curves and branches, because each of these points requires, as a rule, the constant attendance of a workman.

(426) These general remarks require to be completed by a few details.

The driving pulley should be constructed in such a manner that it can transmit the power to the chain without the least slipping.

For this purpose either several turns are made round the pulley, or else its groove is armed with feet or forks, which seize the links.

The return pulleys do not require any particular arrangement.

These pulleys are placed at such a height that the chain is above the top of the waggons as it leaves them. The waggons are engaged by simply pushing them along the road until they come in contact with the chain as it gradually gets lower. (Fig. 312.)

The waggons are dragged along, either by the mere friction due to the weight of the chain, or by means of a kind of fork attached to the edge of the waggon, in which the links of the chain get caught.

The waggons are disengaged in the same way at the other end; they leave the chain of their own accord, and run away either in virtue of their acquired velocity, or in consequence of a slight inclination given to the landing-place at which they arrive.

A similar arrangement is generally adopted for making them pass round a curved part of the road. At a point of this kind a pulley is placed in a suitable position to lift the chain off the waggons as they approach; the waggon becomes free for an instant; but the curved part of the road has a sufficient slope to cause it to run until it again comes under the chain beyond the curve which the pulley has caused it to describe. (Fig. 313.)

Although this change of direction can be effected automatically on both roads in the manner indicated, it is usual to station a young workman at these points, as we have said above, for the purpose of watching waggons as they pass, and preventing disorders, which would ensue if a single waggon got out of its place.

The most simple arrangement for a branch line appears to be to fix a return pulley at the junction, armed with forks to prevent the chain from slipping, and to have two other driving pulleys on the same shaft with it; one for continuing the straight chain, the other for working the branch. The whole will be fixed above a branch-plate of sufficient size to enable a waggon coming from one side of any of the chains to be directed by hand under the proper chain which has to receive it.

When there are many branches at the same point the principal return pulley carries some beveled wheels, which transmit its motion to the driving pulleys of the various branches.

Figure 314, which is an example of the transmission of motion to two oblique branches, will give an idea of these combinations.

It will also be found convenient to make branch lines start off from points where there are curves, because then the same workmen can attend to both services.

In order to make a station on the main ways, all that has to be done is to lift the chains up for a certain distance by means of pulleys. At this part of the road there are no rails, and their place is taken by a branch turn-plate, which permits a waggon to

be inserted into, or extracted from, the file of those that are moving along the road.

The pulley is not, however, in operation except when the station is being used as such. This system is represented in figure 315, which is similar in principle to figure 313.

(427) The system of endless ropes, again, is employed in England under two other different forms, which are analogous to the two systems that we have described.

In both cases ropes of steel, or iron wire, are employed instead of chains.

The first combination is very similar to the system of haulage described in No. 419. It can be worked either with one or two lines of rails.

The machinery will generally consist of a steam-engine with a fly-wheel provided with a brake, and a pulley similar to the one described in No. 411 (fig. 291), with several grooves for the prevention of slipping.

After passing round this pulley and its companion, the rope is bent upon a pulley placed at the near end of the plane, traverses its whole length, is brought round another pulley at the far end, returns towards the engine, and before again passing on to the driving pulley it goes round another large pulley fixed on a movable carriage, which, being acted upon by a counter-weight, serves to give the required tension to the system, and prevent slipping on the driving pulley.

Figure 316 gives a general idea of the system applied to a double road.

In the case of a double line of rails the endless rope is constantly moving in the same direction, and is never stopped for the purpose of shunting, or attaching or detaching waggons; the trains, whether of empty or full tubs, seize it or let it go when it is moving at its ordinary rate. For this purpose it is necessary to have a special carriage at the front, in which the conductor stands or sits, and by moving a handle which works a series of levers he can hook the train on or off; and after he has unhooked it he can bring it to a standstill by means of a brake. He takes care to

unhook at a certain distance before arriving at his destination, and then he is carried to the desired point by the acquired velocity, modified by an application of the brake. This is learnt by practice.

Figure 317 represents a conductor's waggon; but we must refer the reader to the explanation of the plates for a description of it.

Figure 318 represents another arrangement for attaching the train to the rope while it is in motion.

With the above system worked on a double road, we can have several full and several empty trains traversing their respective roads at the same time, and consequently it is possible to obtain a large output in this way *independently, as it were, of the distance to be traversed,* provided the motive power be sufficiently great.

When there is only one line of rails, the rope must naturally move alternately in opposite directions, and come to a standstill at the end of each trip.

With this last arrangement we can dispense with the employment of the special means referred to above (fig. 317 and 318), and attach the trains by means of short pieces of chain to eyelets intercalated, here and there, in the endless rope. A single piece of chain is used at the front of the train, when the work to be done consists altogether of traction, either up hill or on the level; but a piece is required at each end if there are ups and downs on the road.

This method of haulage appears to be at least quite as advantageous as the tail rope system. It takes even a shorter length of rope (in the proportion of 2 to 3, as can be easily seen).

It requires a little less motive power, since that part absorbed by the friction of the brake of the drum out of gear in the tail rope system is here saved. But it is not so suitable with curves, and hardly at all with branches.

(428) The second system of endless ropes operates under the same conditions as the endless chain of No. 425; it is a simple substitution of a smooth rope for a chain; and as such necessitates the adoption of a different mode of attachment. The forked claw on the upper edge of the waggon which will catch a chain does not answer for a rope. It is necessary to fasten on the train by one

chain in front if the slope is always in the same sense, and by two chains, one in front and one behind, if it varies. These chains are easily attached by a turn of the hand without stopping the rope, which, however, travels pretty slowly. Loops of hemp-rope may also be fastened to the endless wire rope at given intervals, into which the hooks of short coupling chains can be passed. (Fig. 319.)

Sometimes single waggons, sometimes short trains of five or six waggons, are hauled along in this way. The system is nearly equivalent to the endless chain. It may require, perhaps, a rather smaller expenditure of power, since the weight of the rope is less than that of the chain; but, on the other hand, the chain lasts longer.

(**429**) In recapitulating what has been said in Nos. 424 to 428, regarding the four systems of haulage there described, we can distinguish the first system, in which *two ropes* are employed, from the three others in which *one endless rope or chain* is used; or again, in the first and third systems we have a rope *trailing on the floor* while the *waggons are carried in trains at a great velocity*, and in the second and fourth we have a *hanging-rope or chain*, by which *single waggons* or *very small trains* are carried *at a slow velocity.*

In considering the four systems we are led to make the following observations:

1. *As regards the cost of construction and keeping the galleries in repair*, the systems by which large trains are carried at a high rate of speed (Nos. 1 and 3), make it incumbent that the lines of rails should be laid with great care, and kept in perfect order, and present but little alteration of gradient.

2. *As regards the price per mile of road, including the cost of the rope*, it is evident at first sight that the first and third systems require only single roads, while the second and fourth must necessarily have double ones; the two former may, therefore, be less expensive than the two latter for the road properly so-called. The advantage of the first is, however, less than that of the third, inasmuch as the latter does not require so long a rope; for in the first

the front rope must be as long as the engine plane, and the tail-rope twice as long, while, on the other hand, the endless rope requires only to be twice the length of the plane altogether. As to the ropes or chains themselves, the superiority is shared equally by the first and third systems, especially over the second, since the chain is much heavier and dearer per yard.

3. *As to the amount of rolling stock*, the first and second systems are preferable for great distances, and the second and fourth for short distances.

4. *As to the motive power required*, the second and fourth systems, with a low velocity, are incomparably preferable to the two others, for the reasons given in No. 425.

5. *Lastly, as to the cost of keeping in repair, consumption of fuel, and manual labour*, the second and fourth systems, especially the second one (the endless chain), are preferable to the others, except where there are numerous branches to be served.

We should therefore decidedly employ :—

1. No. 1 system, with two ropes, in an extensive mine, where there will have to be many stations or branches at different points, and where, at the same time, none of the roads to be served present too abrupt curves, or gradients which vary considerably.

2. The endless rope system, travelling at a high velocity, in preference to the first, as being economical both of motive power and manual labour, if, under the same conditions as those supposed above, there are neither stations nor branches to be served.

3. The endless rope or chain system, travelling at a low rate of speed, and notably the endless chain, when the roadway is sufficiently regular in plan; that is to say, with curves of great radius, but more or less undulating in elevation.

Such are, it appears, the general conclusions that can be drawn from a study of the different systems.

(**430**) We append a table which may give an idea of the mean results determined in the report referred to in No. 423, wherein the respective advantages and disadvantages of the four systems are set forth in figures, under the conditions observed by the authors of the report.

I. AVERAGES PERTAINING TO EACH SYSTEM.

	Description of the Systems Employed.			
	Tail rope. High Velocity.	Endless Chain.	Endless Rope. High Velocity.	Endless Rope. Low Velocity.
	No. 1.	No. 2.	No. 3.	No. 4.
Tons of coal led per day of 12 hours .	476	451	384	443
Average distance traversed in yards .	2133	1389	922	849
Mean ascending gradient for full tubs .	1 in 213	1 in 59	1 in 48	1 in 36
Cost per day for labour . . .	27s. 7d.	13s. 8d.	17s. 9d.	30s. 1d.
Number of tubs in each train . .	59	...	31	1 to 6
Speed of tubs in miles per hour . .	9·54	2·07	6·58	1·12
First cost of waggon-way per mile .	£723	£941	£820	£893
First cost of the engines, boilers, &c. .	£1105	£276	£553	£973
Horse-power of the engines . .	112·36	20·2	62·28	29·01

II. COST PER TON PER MILE IN PENCE.

Ropes or chains	·276	·083	·263	·252
Maintenance of way and rolling-stock	·462	·468	·541	·726
Coal	·558	·256	·237	·323
Labour	·583	·572	1·020	1·692
Total Cost	1·879	1·379	2·061	2·993

The above table gives rise to two principal remarks.

In the first place, it must be borne in mind that the corresponding figures of the four systems do not exactly measure their relative value, because they apply to essentially different local circumstances.

Thus, for example, we have a mean horse-power for the first system of 112·36, for the second that of 20·2;

but the theoretical work done in the first case is $476 \times 2240 \frac{2133 \times 3}{213}$

$= 32{,}029{,}097$ foot-pounds, and in the second $451 \times 2240 \times \frac{1389 \times 3}{59}$

$= 71{,}350{,}240$ foot-pounds. From this we conclude that the endless chain has absorbed *much less power* than the tail rope system, although *the theoretical work done is much greater.* This is no doubt due in some measure to the fact that the distance traversed is less; but more especially to this fact, that, with the endless chain, we

have not to take account of the dead weight of the tubs, and that the resistance to be overcome by the engine is regular.

The various results given in the tables should be taken as examples, and not as actual terms of a comparison instituted between the different systems as applied under the same circumstances.

(431) The second remark relates to the price of haulage per ton per mile.

We see that the above figures are comparable with, and even superior to, those given in No. 403 as the cost of haulage on railways by means of horses.

It is necessary, however, to bear in mind, *in the first place*, that in the figures given in No. 403 nothing was charged for maintenance of way and rolling stock, for which from ½d. to ¾d. is charged in the foregoing table; and, *in the second place*, that in the table just referred to, instead of having level roads to deal with as in the examples of No. 403, we have inclines sloping in opposite directions, the least of which would at the smallest estimate quadruple the resistance met with on the level, and reduce the useful effect of a horse in the same proportion.

It may, therefore, be assumed that, in general, there would be no advantage in substituting mechanical haulage for a good system of haulage by horses on *level* railways, that is to say, on those having a perfectly regular slope approaching that of equal resistance, such as can be constructed in large cross-measure drifts; but that, wherever there may be undulations more or less irregular and discontinuous, which cannot possibly be avoided by laying out the road to the best advantage, and where, moreover, large quantities of mineral have to be carried great distances, the mechanical system may be adopted with advantage.

From this point of view we can say, that seams which are nearly horizontal, only slightly undulating, and divided into distinct districts by faults, are not in the same conditions as those with a *more pronounced dip*, which can be broached successively at different levels by large cross-measure drifts, and in each of which headings can be pushed forward so as to clear a given fault, at

the same time easily retaining a constant slope in longitudinal section.

The first kind of seams are most suitable for the application of mechanical methods of haulage.

The second adapt themselves better to the construction of large main roads, with regular slopes upon which haulage with horses can be advantageously carried on.

We have here, undoubtedly, one of the reasons why mechanical haulage is now, *and certainly always will be,* much more widely adopted proportionately, firstly, in English collieries, and secondly, in German ones, than in the majority of the collieries in other parts of Europe.

CHAPTER XVI.

ON WINDING OPERATIONS IN GENERAL.

(432) We shall suppose that the minerals which have been transported by the means described in the two preceding chapters have not arrived at the surface, either by levels, or self-acting inclines, or sloping drifts, but at the bottom of a vertical, or nearly vertical, shaft, through which they still require to be lifted to the surface.

This operation of lifting the mineral is known by the name of *winding*.

The place where the minerals arrive at the bottom of the pit is called the *pit bottom*, the *hanging-on-place*, *onsetting place*, *plat* (Cornwall), *lodge* (Wales). It is from here that the minerals are raised in the shaft, and arrive at the surface, or at a point below the surface, but connected with it by a level drift, and called the *bank* or *landing-place*.

The object of this chapter is to give a full description of this operation of *winding* or *drawing* minerals.

There is no doubt that great improvements have been effected in winding during the last forty years. Not only has more powerful machinery been erected as the depth and output have increased, but the details have also been perfected to a very high degree.

Indeed, it may be said that there is *hardly anything in common* between the arrangements that were employed, for example, in the departments of the Nord, the Loire, and elsewhere before 1840, for the purpose of winding from thirty to one hundred tons of coal

daily, and those that are in use at the present day in the well-equipped shafts of the same localities whose mean depth is much increased since that time, while the outputs now required from them are three or four times as great, and even more, notwithstanding the augmentation of depth.

The operation of winding requires, therefore, to be studied carefully. If well organized, it has an important influence on the prosperity of a mine; and the arrangements for winding ought to be made on such a scale, that there shall be no difficulty in increasing the output to any desired extent compatible with the extent of the workings. As a rule, no comparison can be made between the *additional cost* of a more perfect equipment and the *additional profit* that will accrue from an increased output, provided the workings are extensive enough to afford the extra supply.

As in every other mechanical result which requires the intervention of a machine (*Cours des Machines*, No. 1), we have to study, in the first place, the various prime movers that can be applied to this operation, and the intermediate machines suitable for receiving their action; then, the organs of transmission, by means of which the action of the motor is transmitted to the operator; and, lastly, the *operator itself*, which in the present case is the bucket or cage which receives the mineral. In this study we must naturally include the accessory arrangements connected with the pit bottom, the lining of the shaft, and the landing-place at the surface.

We shall speak in the first place of the prime movers.

§ 1. Motors and machines employed in winding.

(433) Theoretically, as we have already remarked in No. 34, *Cours des Machines*, two motors of any description whatever are *equivalent*, in a mechanical point of view, when they produce the same amount of work; so that, *a priori*, and in a general way, there is no kind of superiority to be attributed to a motor of a certain nature over another in this point of view. But when it

comes to applying it to a given object, it is not only permissible, but necessary, to compare the different motors, both as regards the *cost of the work* which they are able to perform in the particular case, and also as regards the *daily quantity* that can be got from them, compared with what we require in order to obtain the industrial result we have in view.

If we take the case of a mine whose depth and output are by no means excessive, say a depth of 328 yards (300 metres), and an output of 295 tons per day (300 metric tons), the corresponding amount of work done daily is $328 \times 3 \times 295 \times 2{,}240 = 650{,}227{,}200$ foot-pounds ($300 \times 300 \times 1{,}000 = 90{,}000{,}000$ kilogrammetres), which represents the work of 90 horses on a gin, or 643 men at the windlass, supposing their useful effect per day to be what we represented it in the preceding chapter—7,233,140 foot-pounds for a horse at a gin, and 1,012,639 foot-pounds for a man at a windlass (1,000,000 and 140,000 kilogrammetres). We should still find that 346 men were required, supposing they were made to work with their weight under the best possible conditions at the rate of 1,880,616 foot-pounds (260,000 kilogrammetres) of work. (*Cours des Machines*, No. 39.)

The number of men required would rise to 1,600 if they carried the mineral on their backs, as is still done in many mines in Mexico and South America, and even in backward European countries, like Sicily; and it would be still higher, if the mineral were raised by shovelling it up, or wheeling it in a barrow.

Without even considering the last figures, and merely confining ourselves to the question of applying such intermediate machines as windlasses with handles, tread-wheels, or horse-gins, we see at once the *absolute impossibility* of erecting them at the *mouth of one pit* in sufficient number to be acted upon by so many living motors, and consequently we should be obliged largely to increase the number of shafts if we desired to employ them. From this it follows that the cost of first establishment would be greatly increased; and the employment of so many men or horses is inadmissible, not only because of the great daily expense of keeping them, but also on account of the difficulty, or even impossibility, of bringing so many together.

This conclusion could have been prognosticated after what was already said in No. 420 regarding the application of these motors to haulage from dip inclines, where, moreover, the amount of work to be done is small relatively to that required in a shaft of considerable depth.

We can therefore accept it as an *established fact*, that our great mines could not be *carried on* if the winding operations were done by animated motors.

It should also be remarked, that minerals are not the only substances that have to be drawn out of a mine. It is necessary in some mines to raise quantities of water, which are equal, and sometimes greatly superior, in weight to the mineral. It is also necessary to put large masses of air in motion through the mine, and this again absorbs power; and so on.

Thus the existence of a large mine *necessarily implies* the application of natural motors other than animated ones.

The latter will therefore only be employed in drawing from *shallow and unimportant* pits.

In these cases it will be possible to employ men when not more than three or four are required at the handle; for they will not cost more than a horse with his driver and the special lander required, in the case of a horse-whim, at the top of the shaft for the purpose of receiving and emptying the kibbles on their arrival.

Wherever the work of winding is sufficient to utilize the power of one horse, a horse should be employed; for it can do the work of nearly seven men, and does not cost more than two or, at the most, three.

Similarly, when the work will necessitate the employment of two or three horses, while at the same time fuel is obtainable, or does not cost an excessive price (as it frequently does on the Continent), it will usually be found that a small steam-engine, with all its expenses for an engine-man, fuel, and other kinds of outlay, can be advantageously substituted for them, and more especially when the work is going to last long enough to make it worth while to bring the small engine to the place, and set it up.

(434) The question of passing from one kind of motor to another more economical one, as the amount of work increases, should be examined in each special case, and the limit to which it is advantageous to carry this substitution depends on local circumstances.

Let us take a pit in course of sinking as an example:

Let x be the depth of the pit in feet

A its section

h the amount sunk daily

d the density of the rock, or rather the weight of a cubic foot

Q the weight of water raised in 24 hours.

The daily amount of work that has to be done independently of raising and lowering men, and letting down materials for timbering or walling, is expressed by

$$(d\,A\,h+Q)\,x.$$

It will, therefore, require the number of men denoted by

$$\frac{(dAh+Q)x}{1{,}012{,}639}=N,$$

and the number of horses by

$$\frac{(dAh+Q)x}{7{,}233{,}140}=n.$$

We may assume, as we did above, though of course the opinion may be modified on examining the details of the case, that it will be advisable to substitute the horse-gin for the windlass when more than *four men* are required to work it, and the steam-engine for the horse-gin when it requires *more than three horses.*

Putting therefore

$$\frac{(dAh+Q)x}{1{,}012{,}639}=4\ \therefore\ x=\frac{4\times 1{,}012{,}639}{dAh+Q}$$

$$\frac{(dAh+Q)x}{7{,}233\ 140}=3\ \therefore\ x=\frac{3\times 7{,}233{,}140}{dAh+Q}$$

we shall find the depths x, at which it is best to substitute one motor for the other. These depths will be less according as the shafts have a greater section, the daily advancement is more, and the amount of water to be raised is larger in quantity.

This is the natural result.

If we put $A = 132$ square feet (12·50 square metres), that is to say, a shaft of about 13 feet (4 metres) in diameter,

$h = 1\frac{1}{3}$ foot ($0^{m}\cdot40$), or a monthly rate of sinking of about 12 yards;

$d = 170$ lbs., a common figure for many kinds of rock;

$Q = 7{,}920$ lbs., or 33 gallons ($1\frac{1}{2}$ hectolitre) of water an hour, which is a very moderate amount.

We find $d\ A\ h + Q = 37{,}840$ lbs., and consequently

$$x = \frac{4 \times 1{,}012{,}639}{37{,}840} = 107 \text{ feet, or nearly 36 yards.}$$

$$x = \frac{3 \times 7{,}233{,}140}{37{,}840} = 570 \text{ feet, or 190 yards.}$$

If we supposed the quantity of water to be decidedly noticeable, say 110 gallons (5 hectolitres) per hour, the quantity $d\ A\ h + Q$ would then become equal to 56,320 lbs., and the two values of x would become:

The first $x = 24$ yards.
The second $x = 128$ yards.

These depths are sufficiently large, and at the same time differ enough, to show the advisability of beginning the shaft with a windlass, then carrying it on with a horse-gin for a certain time, and, lastly, erecting a sinking-engine.

This is the usual course followed in practice.

(**435**) Having shown by the considerations, and the numerical examples discussed above, how restricted is the field in which it is either convenient or possible to make use of animated motors for permanent winding purposes, it now remains for us to consider hydraulic and steam motors.

The various forms of hydraulic motors which can be employed for winding are pointed out in Nos. 309 to 312 of the *Cours des Machines.* With the tendency which exists to increase the individual output of a pit, either by greater activity in a given field of operations, or by widening that field itself, it appears to us that the machine which seems destined to become the most common is the *double acting water-pressure engine.* It possesses the advantage of

being able to utilize the whole power of any height of fall. It can also be easily worked at any distance, so as to effect all the changes of motion required by the various operations of receiving cages and sending them away, both from the top and bottom of the shaft; and lastly, the choice of positions where it can be erected is far wider than with the other hydraulic motors.

We consider it to be pre-eminently *the winding engine* that should be employed wherever a natural fall of water is obtainable, or where one can be created artificially by means of an adit level, except in those cases that are not common in mines, where there is a large volume of water with a low fall; the cylinders required would then be so large that it would be preferable to employ a turbine or a breast wheel.

We must now examine the double-acting water-pressure engine in the same way as we have just done with animated motors, so as to estimate the amount of work which it is capable of performing.

In a deep mine with a large output, which has, for example, a depth of 600 yards (600 metres), and an output of 500 tons (500 metric tons) per day, the daily work that requires to be done amounts to $600 \times 3 \times 500 \times 2{,}240 = 2{,}016{,}000{,}000$ foot-pounds ($500 \times 600 \times 1{,}000 = 300{,}000{,}000$ kilogrammetres). Moreover, the exigencies of mining usually make it necessary to draw the whole of the output during *a single shift*. It has been customary to have this shift lasting for 12 or 14 hours; but the constant tendency on the part of the workmen to reduce the hours of labour will, no doubt, oblige it to be diminished to 10 hours; so that it will be prudent, in making calculations about a winding engine, to consider that its work must be done, say in 10 hours daily, which the necessary deductions for stoppages and time lost between the operations will further reduce to 8 hours of effective work. We have, therefore, an amount of useful work of $\frac{2{,}016{,}000{,}000}{8} = 252{,}000{,}000$ foot-pounds per hour $\left(\frac{300{,}000{,}000}{8} = 37{,}500{,}000 \text{ kil.-met. per hour}\right)$ to perform, requiring a theoretical force of $\frac{252{,}000{,}000}{33{,}000 \times 60} = 128$ hse. power $\left(\frac{37{,}500{,}000}{3{,}600 \times 75} = 139\right)$

chevaux-vapeur in useful weight lifted. The power exerted on the piston of the engine must be at least one-fourth more, say 160 horse-power (175 *chevaux-vapeur*) without taking into account the fact, that since the resistance (which we shall consider further on) is not uniform, the engine must be powerful enough to cope with the *maximum resistance* which it has usually to overcome on starting, and not merely with the mean resistance.

Now-a-days, therefore, we must be prepared with engines of 200 horse-power, or even more, for deep pits with a large output. Such pits are already common, and their number will undoubtedly increase rapidly with the lapse of time.

Under the most ordinary conditions, this amount of power (which it would be absurd to think of obtaining from animated motors, for it would absorb the work of all, and often more than all, the men employed about the place) cannot be expected from a fall of water, because such a force is rarely available. We must, therefore, have recourse to steam; and if, as we mentioned in No. 433, our great mines could not be carried on if the operation of winding had to be done with *animated motors*, we could almost add here, with equal truth, that *they could not be carried on without the aid of steam power in winding.*

(436) What is the best form of steam-engine for winding purposes?

It is advisable that we should examine this question here in general terms, and refer the reader for details to the second volume of the *Cours des Machines.*

The principal conditions to be fulfilled are the following:

In the first place the engine should be close to the engine-man, and easily handled while sending away and receiving tubs or cages, although the mean velocity of winding must be great.

These objects are attained by using an engine with two cylinders connected together, and provided with a light fly-wheel, which serves rather the purpose of a *rim for the application of a brake* than for regulating the speed. The latter is not an important matter; and, besides, it is sufficiently effected by the mass of the drums and ropes, as well as the weight with which they are

loaded. With these arrangements the engine can be stopped, started again, or reversed very promptly; in short, it can carry out all the necessary operations for raising or lowering the cages, both at the top and bottom, without our being inconvenienced by the inertia of a fly-wheel, or having to fear any dead point, which would sometimes make it necessary to push round the fly-wheel in order to start the engine.

The employment of two cylinders driving one shaft has not been many years in vogue at mines. It must be considered as one of the most interesting improvements that have been made in winding-engines, allowing them to be handled with the same precision as a locomotive.

In the second place, the engine ought to be simplified as much as possible with the view of diminishing the chances of its stoppage, and assuring the certainty of its action, by reducing the number of the parts which ought to have their surfaces in a perfect state, and are not always in sight, such as the valves, pistons, stuffing-boxes, &c. The service of haulage especially, and to a certain extent also the work of getting mineral at the faces, cannot go on regularly unless the winding is carried on properly.

In order to obtain this great simplicity, it has been usual to work at high pressure without condensation, and without expansion, or at any rate without a special arrangement for expansion, save what is obtainable by a certain lead of the slide-valve, and the corresponding lap.

For the same purpose, and also with the view of reducing the original cost, and the expense of erection, Watt's beam, together with all its connections, has been done away with, and the connecting-rods of the pistons are attached directly to the cranks of the fly-wheel shaft. The cylinders are sometimes placed horizontally, sometimes vertically; and, after taking into account their respective advantages and disadvantages, no marked preference has yet been given to either system.

Pursuing the same order of ideas, the drums for holding the ropes have been fixed on the fly-wheel shaft, whilst the gearing, which in the old system served to drive the drum-shaft slower than the fly-wheel shaft, has been suppressed. By

having thus only one principal shaft, it has been possible to do with only one powerful brake, worked by means of a counterpoise, or better still by steam, and capable of stopping the machinery instantly. In this way we escape the consequences which a breakage of cog-wheels would entail if there were merely a brake on the fly-wheel.

It will be remarked that the suppression of gearing cannot be altogether defended from a theoretical point of view. It is even contrary to the most approved system of the present day of having light and rapid engines, such as are now employed in many industries; but it is almost universally practised in mines, at least for engines of one hundred horse-power and upwards.

A winding-engine, established according to the ideas most in favour in France and Belgium during recent years, has therefore the following construction:

1. It has two cylinders, horizontal or vertical, without condensation, and with a very feeble expansion produced by lead and lap.

2. The pistons are connected directly to the fly-wheel shaft without the intervention of toothed gearing.

3. The fly-wheel is light, and the brake, which is often a steam one, acts on its rim, and is on the same shaft as the drums.

4. Lastly, it has reversing gear similar to that employed in locomotives; that is to say, Stephenson's link-motion, or one of its derivatives, provided with one of the well-known arrangements for enabling it to be easily moved without requiring too great an effort on the part of the engine-man.

An engine fitted up in this manner ought to have a *large margin* of power, so that there may be no difficulty in starting or stopping and even *working with one rope.* We must remark that this last condition is not an extra precautionary measure to serve in case of accident. In reality it comes into use regularly at the end of each operation; for the cage at the bottom is already resting on the *keps* at that point before the cage at the top is landed.

The type of engine described above is considered by managers of mines and engine-makers to fulfil satisfactorily all the conditions which are considered requisite in a machine of this kind.

(437) It is easy to see, however, that this list leaves something to be desired in an essential point of view, the importance of which increases in proportion as the power of the engines goes on augmenting, and more especially in these recent years, when the price of fuel, even of inferior quality, employed on the spot where it is produced, has increased to a point from which it will not readily descend to its former value.

The point of view referred to is the consumption of fuel, which, under the circumstances enumerated in the preceding number, is necessarily very high, and gives rise to a rapidly increasing expenditure of money, partly owing to the price of the extra fuel consumed, partly to the accessory expenses of manual labour, and the erection and maintenance of boilers involved by this great consumption relatively to the force actually utilized. This excessive consumption is due principally to three causes:

In the first place an engine with an *ample margin* of power, as we have said, is one that should be able to start *in every position;* for example, when one piston is at its dead point, and the other at the middle of its course; and this is, as we know, the most unfavourable position for the action of the steam upon the pistons.

It is necessary to move from this position, even in the most difficult circumstances; for example, if it happened that a full cage had to be lifted off the bottom without the counterbalance of the other cage, or, as already pointed out, if the empty cage is resting on the fangs at the bottom of the shaft, and the full one has still to be raised a little before it can be properly landed at the surface.

The pistons, therefore, have to be made of sufficient size to obtain these results with one of them standing at the middle of its course while the other is at its dead point; at the same time applying the whole pressure in the boilers.

The pressure that might be required under these circumstances, and in these special positions of the pistons, is obviously more than sufficient for the ordinary operations of winding, so that it has necessarily to be reduced by wire-drawing in the throttle-valve.

In these conditions we have an engine working with neither condensation nor expansion, at a reduced effective pressure, and

consequently at a greater or less relative loss in consequence of the counter-pressure of the atmosphere.

It is therefore quite necessary, while *making plenty of allowance,* as we have said, to avoid going too far; for all that is done over and above is mischievous, since it obliges us to check the working pressure. Cases have come under our observation in which, *under the pretext* of being prepared for a probable great increase of the depth or output, or as it was put, for the purpose of *insuring the future,* the pistons were made so large that the engine was able to do its work with an effective pressure amounting to half an atmosphere, while that in the boilers was equal to four or five.

It is quite certain that, if we insure the future in this way, it will be *at the expense of the present;* for with half an atmosphere of effective pressure a non-condensing engine loses two-thirds of its power in consequence of the counter-pressure of the atmosphere.

In the second place, an engine in which the steam acts at even a higher effective pressure than we have just named, but without either expansion or condensation, is essentially defective as regards the theoretical employment of the steam; and we cannot be permitted at the present day to neglect this imperfection in such powerful engines as we have to employ, and which cost so much for fuel.

For some years past several skilful engine-makers, and amongst others M. Farcot, have tried expansion gear on winding-engines intended for other than coal mines, and where it was consequently necessary to economize fuel.

But expansion was not, however, made use of to a great extent. It was necessary, in fact, that, when the distributing valves were reversed for the purpose of changing the motion of the engine, steam should be admitted into *at least one* of the two cylinders; but if, after the reversal had been made, one of the pistons was just arriving at its dead point, the other, which was coming at the the same time to the middle of its course, would still require to get steam; and this is equivalent to saying that the admission must be continued *at least during half* the stroke.

With the *fixed expansion gear,* therefore, one could not cut off steam before half-stroke.

Thirdly and *lastly*, as condensing apparatus made the engines a good deal more complicated, people were afraid of employing it; and it was hardly adopted anywhere, except in some of the mines at Newcastle, and in the Ruhr basin, where its value was better understood, and in the Cornish mines, where the price of coal is relatively high; elsewhere high-pressure steam without condensation was universal.

We see, in fine, that the prodigal consumption of fuel by winding-engines of the type we have defined above does not arise from any special causes, and that the means for remedying it are in reality the same as those that would be resorted to in the case of any other kind of steam-engine whatever; namely,

1. To employ expansion gear capable of varying according *to the varying resistance of the work*, so as to make *the motive power developed on the engine per stroke of the piston* proportionate to the resistance.

2. To employ condensation, which enables us to work with a high rate of expansion and to work at a reduced pressure, without experiencing too considerable a loss on account of counter-pressure of the atmosphere.

These ideas are accepted by all persons conversant with steam-engines; and they are all the more applicable in the present case, since we are treating of a machine from which a greater effort may be accidentally demanded at any time than its mean effort when performing its normal work, as is the case with a winding-engine. We are thus obliged, as we have said above, to make a *liberal allowance* in calculating the diameter of the pistons.

Nevertheless, many have refused to apply them to winding-engines, at least to those employed at collieries, under the *pretext* that the fuel was valueless; while at the same time they have exaggerated the importance of *the motive* which might induce one to simplify the machine as much as possible.

(438) However, during the last few years the question of expansion has come to the front, and several engineers, notably M. Audemar, of Blanzy, in France; M. Guinotte, of Mariemont; and M. Scohy, of Montceau-Fontaine, in Belgium, have taken it up frankly.

In reality, if we choose to examine the matter carefully, we see that a good system of expansion gear does not greatly complicate any given engine. In locomotives, it is true, no attempt has yet been made to obtain a variable expansion, except what can be produced by the very imperfect mechanism of the slide-valve. This is no doubt due to the constrained nature of the service to which these machines are applied, exposed as they are to constant shaking, and moving at a high speed relatively to their power. It is quite different, however, with a winding-engine, which is stationary; while its velocity, measured by the number of turns of the fly-wheel, is relatively small as compared with that of most engines employed in other industries; and, lastly, it has this distinguishing character, that the variations of resistance take place periodically during the successive operations of winding.

It may therefore be reasonably supposed that variable expansion gear could be advantageously applied in this case without being in itself the cause of heavy and frequent repairs; and that, on the contrary, it might act very usefully, if arranged in such a manner as to satisfy the following principal conditions:

1. To permit the cut-off to adapt itself automatically, or by some easy action of the engine-man, to the variations of resistance which take place during the winding of a cage, and thus to maintain the desired speed of the engine.

2. To have the means of abandoning the use of the expansion gear altogether *at any moment while a cage is being drawn*, so as to be able to stop, and start, or back the engine in whatever position it may be at the time, or, *at the least*, at both ends of the stroke, in order to allow the operations of receiving and sending off the cages to be carried out properly.

3. To effect these objects without distracting the engine-man by any additional physical effort, or a greater exercise of his mental capacities, since his attention is already sufficiently absorbed.

The true question is, not to add another method to the numerous plans for effecting variable expansion, but to choose some one method, and make such alterations of the details, as will fit it to fulfil the general conditions that have been laid down.

(439) M. Audemar has chosen a system of expansion gear that has long been known, which consists in interrupting the admission in the slide-valve box by closing a valve.

This valve has a double beat, to enable it to be easily opened; and it is moved by a lever, which in its turn is acted upon by a cam coupling-box, receiving a rotatory motion from the engine-shaft. The coupling-box can slide along its axis; but it is so connected with the lever working the ordinary link motion that one cannot be moved without the other.

The latter, when placed in its two extreme positions, may be considered as serving the purpose of setting the slide-valve in the proper position for raising or lowering.

At the same time, when it is in these two extreme positions, the link-lever will bring the coupling-box into such a position that the cams occupy the entire circumference; thus the cut-off valve remains open during the whole stroke, and there is no expansion.

If the link-lever is moved from these extreme positions the coupling-box changes its place, and the lever of the cut-off valve is then in relation only with a length of cams, occupying less and less of the total circumference, and consequently the admission diminishes until it becomes *nil* at the same time as the angle at the summit of this sector disappears. In this way, by a small movement of the link-lever, we succeed in passing through all the degrees of expansion from an admission during the whole stroke to none at all.

By this contrivance the engine-man suppresses the expansion altogether when he places the link-lever in one of its extreme positions; the engine goes backwards or forwards according as the lever is in the one or the other of these positions; the admission is altogether stopped even before the lever is brought to the middle point; lastly, when the engine is in motion it can be made to go at the desired speed by placing the lever nearer to, or farther from, its extreme position.

Matters are so arranged, besides, that a *very small* travel of the lever, *hardly* altering the position of the slide-valve relatively to the ports of admission and escape, suffices to move the jaw from

the position which corresponds to an entire admission to that which corresponds to no admission. The result is that the engine is very sensitive to displacements of the lever, and that the various degrees of expansion are regularly obtained, although the slide-valve remains almost in its normal position.

An example of the arrangement, of which we have here given a general idea, is represented in figure 320, but we must refer to the explanation of the plates for its further description.

(440) M. Guinotte has based his method upon Meyer's variable expansion gear, which is distinguished by having two superposed slide-valves with a certain relative movement. The lower slide-valve corresponds to what is called a normal slide-valve, and the plates of the upper one can be kept at a variable distance apart, and so made more or less promptly to close the admission openings which traverse the first. (See the *Cours de Machines.*)

M. Guinotte has modified the valve by making it of a single plate *and varying its stroke*, instead of having, like Meyer, a *variable size* and a *constant stroke.*

In order to understand the system we must conceive that the lower slide-valve is an ordinary one, and that the link with which it is provided is for the purpose of placing it, at the two extremities of its stroke, in connection with one of the two eccentrics, corresponding either to the forward or backward motion of the engine.

We now come to the manner of working the expansion slide-valve. But we know that with an ordinary slide-valve we can close the admission port at various points of the stroke of the piston, provided we give the eccentric which works it the *proper radius*, and key it at the *right angle.*

In order to have a variable cut-off it will be necessary to produce upon the cut-off valve, while the engine is in motion, the equivalent of a variation of these two elements. We know that this result can be obtained by communicating motion to the cut-off valve, not from a single eccentric, but by means of a link actuated by two eccentrics. This is, indeed, the principle of Stephenson's link-motion, and its numerous modifications; accordingly, in the same way as the stroke of the ordinary slide-valve can be altered by

means of the link, it is possible, by a similar device, to vary the stroke of the cut-off valve from its mean position, which corresponds to the dead point of the piston, and thus to close more or less quickly the ports by which steam is admitted into the lower valve.

Such, then, in its most elementary form, is the combination which has been devised by M. Guinotte. At first sight, it appears to necessitate the employment of two links and four eccentrics—an arrangement which might perhaps be found somewhat complicated in a locomotive, although it has been made use of, but one which, in the case of a winding-engine, would be perfectly admissible.

But the system may be simplified and modified in a great variety of ways, in accordance with geometrical principles, into the details of which it is not within our scope to enter here, but which have been set forth both by M. Guinotte himself in a pamphlet, published at Liege in 1872, and, more recently, by M. Pichault, in an article inserted in the *Annales Industrielles* (January, 1874).

Figure 321, copied from the above-mentioned work of M. Guinotte, represents the arrangement which has been adopted for a winding-engine at the mines of Mariemont. There are only two eccentrics, as if the engine were without expansion, and the other gear consists of one additional link motion, and several rods and levers, which, although they may appear somewhat complicated, do not really add to the danger of the machinery getting out of order. By this arrangement the cut-off can be varied automatically during the raising of a tub according to the variation of the moment of the forces in action, while it can be suppressed momentarily during one or two strokes at the beginning and end of a winding operation.

(441) M. Scohy's system applies essentially to an engine having four slides, two for admission and two for exhaust, like that which has been selected as an example of the application of M. Guinotte's system.

It may be here mentioned in passing that this arrangement has of late found favour, on account of its twofold advantage of

allowing of larger ports for admission and exhaust, and at the same time rendering the hand regulation more easy than it is in large engines, working at a high pressure, when fitted with the ordinary slide-valve.

M. Scohy's system of variable expansion consists in cutting off in the steam-chest, not by means of a valve, but by a little auxiliary slide or cut-off slide, which is so connected that the radius of its eccentric is parallel to the crank, and that this cut-off slide always moves in the same direction as the piston.

Its port is full open at the dead point. The cut-off takes place when the slide covers the port, and the expansion continues until the end of the stroke.

In the back stroke of the piston the port again opens; but at this moment the corresponding admission-slide is closed, so that the steam cannot again pass on to the piston until the end of the stroke.

The degree of expansion can be varied, as in Mayer's system, by means of a little hand-wheel, which turns a rod having screws cut opposite each of the expansion-slides. The threads of these screws are in contrary directions, so as to cause the two expansion-slides to approach or recede from each other, and thus to change their positions relatively to their respective ports. Lastly, the expansion may be dispensed with altogether, during the operations at the arrival or departure of the cages, by the use of two other little slide-valves, placed by the side of the expansion-slides, but which are independent of them, and capable of being opened or closed at pleasure.

This last movement may either be effected by the engine-man himself, or may be accomplished automatically by means of two tappets suitably placed upon a wheel, which is driven by an endless screw, and which accomplishes a little less than one revolution in each complete run. One or the other of these tappets near the end of each run opens the slide-valve, and dispenses with the expansion during the requisite interval; and counterbalances are so arranged as to restore the slides to their ports, and thus re-establish the expansion, as soon as the tappets have ceased to act.

By lifting up the weights of these counterbalances the expansion may be dispensed with during the entire run.

It would be difficult *à priori* to give a decided preference to any one of the three systems of expansion gear which we have just described. But this much may be said, that the application of variable expansion to engines which have to be reversible, and capable of varied movements, as winding-engines require to be, may now be considered as a problem which has been solved in practice, and in several different ways.

It may be expected that these methods, and others more or less analogous to them, which are certain to be invented, are destined speedily to become *generally adopted.*

(**442**) Can the same be said of that other improvement mentioned at No. 437; viz., the use of condensation?

That is a question of which it may be said, that it has not yet been answered; or perhaps it may even be said with more truth, that in the opinion of the majority of competent judges it would at the present moment be answered in the negative.

Undoubtedly the employment of condensation presents in ordinary engines, certain disadvantages in multiplying the number of working parts, whose rubbing surfaces escape the eye of the mechanic, and have always to be maintained in perfect condition. It is equally undeniable that those disadvantages are increased in the case of machinery, like that employed in winding, which is constantly being stopped and started and reversed in order to land and send off the cages. But, on the other hand, every one is aware that the employment of condensation is greatly conducive to economy of fuel, both *directly*, by reducing the amount of back pressure, and *indirectly*, by the facility which it affords of largely augmenting the degree of expansion, before arriving at that limit to the final pressure which is dependent on the amount of the back pressure.

In our opinion, *the time is not far distant* when the benefits resulting from these advantages will be recognised, even in spite of the drawbacks attaching to the ordinary form of condensers which are worked by the engine itself to which they are applied.

But when we recollect the well-known arrangement of applying a special condensing-machine, either to a single engine or a number of engines, it may be said, we think, that from this moment *the time has already come.* A complete centre of production, destined to be self-sufficient, will often comprise two distinct pits, not far separated from one another, and which will or may be fitted, independently of the winding-engine, with a pumping-engine of a power approaching, or even superior to, the former, a ventilating engine, a special engine for raising and lowering the workmen, besides several auxiliary engines for the repairing shops, for an elevator, or for some apparatus for washing coal or making patent fuel, &c. &c.; so that a great mining establishment may well embrace within a short radius a number of engines of various types, representing collectively a force of *several hundred horse-power.*

All these engines may be reduced to their *maximum simplicity*, by dispensing not only with condensing apparatus, but also with feed-pumps in each of them, and reducing them simply to those parts which are *indispensable to their action as receivers.* All the subsidiary functions are relegated to a special engine, which performs *for all* the double part of feeding the boilers and condensing the exhaust steam.

This engine, having no other office to discharge, may be placed under the most favourable working conditions as regards its special functions. We can thus secure the double advantage of *regularity* and of *economy* in the working of each of the engines employed: regularity, because the engine has been reduced to its simplest possible form; and economy, because it is worked with condensation.

The advantages of this arrangement, great as they may appear, have not been admitted unquestioned. It has been supposed that a *separate condenser* acting *continuously* is ill-adapted to the use of an engine, the action of which, like that of a winding-engine, is interrupted and variable. It has been asserted that it would be necessary to stop it every time that the winding-engine was stopped; and that when that engine was again started, the vacuum not being produced till it had been in action for some seconds, a con-

siderable part of the advantage of condensation would be lost, considering the extreme shortness of the duration of each run, &c.

These drawbacks, which are really only secondary, disappear altogether in the case we have supposed, where the winding engine is only *one of several engines* which are served by the separate condensing engine; and, in short, we do not believe that those objections can have any weight against the economical advantages which would result from the application of condensation of steam to a group of engines which might be of 400 or 500 horse-power, or, under certain circumstances, very much more.

It appears to us, therefore, that the definition which we have given at the end of No. 436 of the type of a winding engine must be completed by adding—fifthly, that the engine should be furnished with *variable expansion gear;* and, sixthly, that it should be provided, at any rate when there are several other engines of more or less importance employed at the same establishment, *with a special engine to do the feeding and condensation* for all.

We believe that the definition thus completed will be admitted almost universally at the present day, except as regards the sixth and last condition, which will encounter, erroneously as we believe, many opponents.

Such is our conclusion, and without entering here into greater details, we would refer the reader for further arguments in support of it to the second volume of the *Cours de Machines.*

(**443**) Referring to what has been said above (Nos. 432 to 442), it will be observed:—

Firstly. Animal power can only be employed for the purpose of winding from shallow depths, beyond which it is *too difficult, and even impracticable, to apply it.*

Secondly. Hydraulic power, when it either exists naturally, or can be created artificially, may, *if there is a sufficient abundance of it,* be employed with great advantage; and, in the present state of the art of mining, the best form of motor appears to be a rotatory water-pressure engine, arranged like a steam winding engine.

Thirdly. Lastly, when there is no hydraulic power at hand, and there is no possibility of creating a sufficient amount, a case which

frequently happens, and will become of still more frequent occurrence hereafter, the employment of steam, under the circumstances above described, is *absolutely indispensable.*

An analogy will be remarked to exist between winding and mechanical haulage from the dip, of which we have treated in the preceding chapter. The only differences are, that, on the one hand, in the case of dip haulage, the friction of the tubs has to be overcome as well as the force of gravity; while, on the other hand, the vertical heights and the quantities to be raised, and consequently the power which has to be expended, are generally much smaller.

Reasoning by analogy, it might be said that the *power transmitted from a distance,* of which we have treated in No. 420, might be applied in the case of winding; that, for example, hydraulic power available at a certain point might be employed to compress air, which might be conducted to a shaft, and employed to drive a winding engine; or that, in a case in which it would be necessary to erect a pumping engine of considerable power in comparison with that of the winding engine, it would be possible to do the winding by means of a water balance, which would lower into the mine a weight of water sufficient to effect the raising of the mineral, &c.

All these combinations, as well as the employment of long endless ropes, or even lines of flat rods, for the transmission of power, may be suitable for certain special cases, and the engineer must use his own judgment in deciding where such applications are advisable.

This will only happen in particular cases, while in ordinary practice, or, as we may say, in the normal state of the case, the solution of the question, in any mine of importance, will be, and cannot but be, the employment of a steam engine, agreeing more or less closely with the type described above.

(444) We have exhibited in the *Cours de Machines,* plates i., ii., and iv., vol. 1, examples of machines for animal power, and on plates xxiv., xxv., xxvi., and xxix. in the same volume, machines for hydraulic power, of the principal types suitable for the raising

of weights, and consequently for winding; viz., in the case of men, the windlass and the treadwheel, in that of horses, the gin or whim, and in that of hydraulic machinery, the water balance, the rotatory water-pressure engine, and the waterwheel with a double set of floats. We shall add, for the sake of giving completeness to these general notions on the subject of winding machinery, drawings of several types of steam-engines, which will give a general idea of them, referring, however, for their theoretical explanation, to the second volume of the *Cours de Machines*, and for the details to the explanation of the plates, which will be found further on. The special older treatises on the subject, for example, that of M. Combes, and even the more recent work of M. Ponson, were published before the introduction of the important modifications which winding machinery has undergone within the last twenty years; and the types which these works represent would in many cases appear antiquated at the present day. We shall reproduce some of them, however, to serve as a basis of comparison, and we shall add several new types.

However, within the last few years descriptions of a great number of new engines have been published, especially in M. Burat's *Matériel des houillères et l'exploitation des Mines*, and in the supplement to M. Ponson's treatise. They are to be found also in various special collections, as in the industrial publication of M. Armengaud, the atlas of the "Société Minérale de Saint Etienne," &c., which may be consulted by those who wish to study these machines more deeply, and to go beyond those generalities to which it is necessary that we should confine ourselves here.

Figure 323 represents a vertical beam engine having one cylinder, and the drums worked by gearing, such as was employed during a period of forty years in the district around Mons. It is the type which is in some respects the furthest removed from that of the present day. The shaft of the fly-wheel carries a pinion which is geared into a spur-wheel on the drum-shaft. Hence it follows that the motion of the *reels* would be very slow, such was suitable for winding unguided kibbles.

In Figure 324, the engine, which was constructed by M. Révolier, has also a single cylinder and gearing; but the cylinder is horizontal,

and drives the shaft directly by a connecting-rod; the engine is, therefore, much simplified, as may be seen on comparing this figure with the preceding one.

Figure 325 represents an engine constructed by M. Quillacq; it is horizontal, has two cylinders, and is direct-acting, having no gearing. The cranks actuate the two extremities of the fly-wheel shaft, which also carries the reels, and the arrangement is remarkable for its symmetry.

Figures 326 and 327 represent two vertical engines, having both the same general arrangement, but distinguished by the greater use which is made of metal framework in the former, and of masonry in the latter.

Finally, the last (fig. 328) represents a sketch of an engine having two vertical cylinders, in which a special mechanical arrangement ensures the perpendicularity of the piston-rods, and causes the reels to turn in contrary directions. Hence it follows that the two ropes may roll and unroll *on the upper side of their reels.* Thus they are bent in the same direction, both on the drums and the pulleys, a condition which is favourable to their duration.

It is known as a matter of fact that in the ordinary arrangements, where one rope laps over, and the other laps under, its drum, this latter wears perceptibly faster, and does not last so long. Notwithstanding this advantage, this type of engine, proposed by M. Colson, does not appear to have come into extensive use; the ordinary horizontal or vertical arrangements are more simple, and of a more general application.

(For figures 323 to 328, see the explanation of plates 55 to 60, where various observations will be found on the advantages and disadvantages of the engines represented.)

§ 2. Intermediate apparatus employed in winding.

(445) The prime mover, of whatever kind it may happen to be, sets in motion a single drum, two drums, or two reels. The single drum is made either cylindrical, or in the form of two truncated cones united by their larger bases; the plan of having two drums

is more convenient for altering the length of the rope. Drums are used for round ropes, and reels for flat ones: the reason of this will be seen further on.

From the drums or reels the ropes pass on to pulleys or sheaves, fixed at the top of a high frame called the pulley-frame (head-gear, poppet-heads, shaft-tackle), and then hang down into the pit. The length of the ropes is so regulated that when one end is at the surface the other is *near*, or at the hooking-on place (*plat*), which is being served. (We say *near*, and not *exactly at*, because, as a general rule, the empty cage is already resting on the keeps at the onsetting place, whilst the full cage is just being lowered on to the keeps at the surface.)

This then is the operation which we have to examine in detail.

We must begin by distinguishing two cases; firstly, where the winding machine is placed near the shaft, a matter which rarely presents any great difficulty when steam power is employed; and, secondly, where it has to be erected at some distance, either at the surface or underground, on account of the water power not being available on the spot. This latter case is a common one in metal mines, and is frequently met with in Germany.

Should we, in such a case, transmit the power from the water-wheel or hydraulic engine to the axle of a drum fixed near the shaft, or is it preferable to fix the drum near the wheel, and carry the rope directly to the head-gear by means of guiding pulleys or rollers?

The old miners preferred the first method; and erected the well-known long lines of wooden *flat-rods*, not only for winding, but also for pumping, and so transmitted hydraulic power, obtained from wheels with a single or double set of buckets, to great distances. The flat-rods were set in motion by connecting rods attached to cranks fixed on the axle of the water-wheel, and the other extremities transmitted the power to connecting rods, which actuated either the axle of the winding drum, or the *bobs* of pumping gear.

Machinery of this kind was often put up with much skill, and sometimes on a very large scale. This system has rendered very great services in its time, and it is still in use in many

places. Various examples are figured in the atlas of *La Richesse Minérale.*

It appears to us that this system has had its day, and that for the future it will be rarely advisable to use it. One great disadvantage is the great loss of power due to the friction of the flat-rods on their numerous supports, and to their vibrations. In the particular case under consideration we think the solution of the problem ought to be the reverse of that which was adopted formerly. It is certainly simpler, and at the same time more economical, both in power and money, to guide two ropes from the machine to the pulleys than to transmit the power by lines of flat-rods. Ropes are guided nowadays for very considerable distances, as we saw in the chapter on Mechanical Haulage, and the operations are carried on under much more difficult conditions than those which would have to be encountered if hydraulic power were used to wind up the comparatively small output of metal mines.

(446) The diameter of the drums or reels around which the ropes are wound must be arranged so as to suit the size of the rope. Thus for large hemp ropes the drums may be made as much as 13 to 16 feet (4 to 5 metres) in diameter. At the same time, in order to limit the size of the machine to as small dimensions as possible, the drum may be made cylindrical, and only slightly wider than is necessary to receive one rope; for in practice, when one rope is wound on the other is unwound, and the total amount of rope wound on the drum at any moment is equal to the length of one rope only.

Figure 329 exhibits a round rope drum, arranged somewhat differently from the last-mentioned; it is twice as wide, and is composed of two truncated cones joined to each other by their bases. The principal object of this arrangement is to assist in making the rope coil on regularly, and it helps also in a slight degree to equalize the load on the engine. The figure shows a small winch, on which the end of the rope is wound for the purpose of attaching it to the drum. The winch itself is fixed by lashing its spokes to an arm of the drum.

Drums for round ropes are generally placed with their axis in a horizontal position, and reels for flat ropes are always placed so. However, vertical drums are sometimes preferred when the same rope has to be used for drawing from several distinct shafts, because by this arrangement the rope can be uncoiled at a tangent in any direction, and can thus be made to pass to any one of the pulley-frames. If these pulley-frames are close by, and at the same height as the drum, the rope may pass on to the sheave directly, but otherwise it must be guided by small sheaves. When there are two distinct drums or reels, the simplest way of enabling the length of the rope to be varied as much as possible, consists in keying one of the drums fast to the shaft, and having an arrangement for setting the other fast or loose at pleasure. This is a very simple mechanical problem, and it is usually solved by keying on to the shaft a coupling-box, around which the centre-piece of the drum can slip with little friction. The centre-piece is made in two parts firmly joined together, and can be made fast to the coupling-box, or allowed to run loose at pleasure.

This system is represented in figure 330, which also shows one of the modes of fixing a flat rope to the reel. It consists in turning back the end of the rope in a recess made for the purpose, and then driving in a wooden wedge sideways.

Figure 331 exhibits a somewhat different arrangement for enabling the drum to be coupled to or uncoupled from the driving shaft. Figure 332 shows another method of fastening a rope to a reel or flat rope drum. It consists in fixing the first coil by means of plates drawn together by means of bolts, which pass through lugs cast on the centre-piece.

The length of the rope is usually such that there are always one or two coils which do not require to be unwound; this arrangement ensures a firm hold, and, consequently, the ropes may *break*, but they cannot become *unfastened*.

(447) The ropes themselves form a subject requiring consideration. Unless ropes properly suited to the work are chosen, they may become a source of considerable expense, either from wearing too fast, or on account of the excess of power required to raise them

in the shaft. Ropes are made either of vegetable fibres (hemp or aloe) or of metallic wires (soft iron or steel).

We have already spoken of *round* ropes and *flat* ropes. The latter are simply made up of several round ropes placed side by side and sewn together. Care must be taken to have an equal strain upon the ropes while they are being sewn together, and it is also necessary to select ropes of exactly the same make, so that they may all stretch to the same extent under a given load. There ought further to be an even number of them, and the twists of two adjacent ropes should be in opposite directions; this gives the flat rope, formed by their assemblage, the appearance of a braid. The object of this arrangement is to neutralize the tendency of each separate rope to untwist under the action of the load.

Without pretending to set forth a theory of the manufacture of ropes for winding, we may remark that they must not be made up, like ropes for suspension bridges, of parallel wires held together by bands. This arrangement would prevent their possessing the necessary flexibility for coiling round the drums or over the pulleys; or, if sufficient power were exerted to coil them, the outermost wires on the convex side would be subjected to an excessive tensile strain, and those on the concave side to an excessive crushing strain, increasing with the sharpness of the bend and size of the rope.

On the contrary, when the wires are twisted while the strands are being made, and the strands while the rope is being made, each particular wire is at one point of the rope on the convex side, at another on the concave side, and at a third in a mean position, no matter how the rope is bent. It consequently escapes the excess of strain which would be put upon it if it were lying entirely on the outside or inside. If, then, we bend a rope of this kind, that is to say, a rope composed of wires and strands twisted together, until we reach the limit of elasticity, we certainly arrive at a limit far beyond what would have been possible if we had submitted a rope made up of parallel wires to the same amount of bending.

We can therefore understand how the fact of the parts being twisted or *laid*, besides ensuring their being kept together in a bundle, contributes to the *flexibility;* and that this increases as the spiral coils of the wires and strands become more and more

inclined to the axis. The ropes thus become capable of resisting, not, of course, a greater longitudinal strain, but a greater tensile strain, at the bends which each part of the rope is subjected to in succession during a complete journey of the cage. The twist produces also another effect; it allows the rope to *stretch* more when it is strained longitudinally, and this property gives it a greater *live resistance* to rupture (see *Cours de Machines*), a matter which is of importance at the instant the load is being raised.

These theoretical considerations are confirmed by practical experience. There need be no fear, therefore, of giving a decided twist, even if it be somewhat at the expense of the *ultimate breaking strength*, in order to increase the *elasticity;* and care must be taken that all bends should be made over curves of large radius, and, if possible, all in the same sense. It is admitted, in fact, that the rope suffers less when it is always bent in one sense, than when it is bent alternately in *two opposite ways.* This has been already stated in No. 444.

(**448**) The relation between the section, weight per metre or fathom, breaking strain and working load, may be deduced from the following data, which refer to well-made ropes without an excess of tar.

1. Each circular section of a hempen or aloe-fibre rope, 1 centimetre in diameter, will bear a load of 300 kilos. before breaking.

2. The weight per metre of a rope properly tarred for working in a winding shaft, but without excess of tar, is about 80 grammes for each circular section, 1 centimetre in diameter in the case of hemp, and 75 grammes at most with aloe-fibre.

3. The working load is taken between $\frac{1}{4}$ and $\frac{1}{6}$ of the breaking strain, or on an average at $\frac{1}{5}$.

If, then, d is the diameter of the rope in centimetres,

P its weight per metre in kilogrammes,

Q the breaking load,

Q′ the working load,

we shall have:

FOR HEMP.	FOR ALOE-FIBRE.
$Q = 300d^2$	$Q = 300d^2$
$P = 0{\cdot}08d^2$	$P = 0{\cdot}075d^2$

and consequently

$$\frac{Q}{P}=\frac{300}{0{\cdot}08}\quad Q=3750P,\quad \frac{Q}{P}=\frac{300}{0{\cdot}075}=4000P.$$

and lastly

$$Q'=\frac{1}{5}Q=60d^2=750\ P,\quad Q'=\frac{1}{5}Q=60d^2=800P$$

If we wish to express the formula in square centimetres of sectional area a, instead of using the diameter, we have simply to lay down the equation $a=\frac{\pi d^2}{4}$; $d^2=\frac{4}{\pi}a$, and therefore the equation $Q'=60d^2$ becomes

$$Q'=60d^2=60\times\frac{4}{\pi}a=76a$$

We may thus lay down the practical rules that the working load of a rope made of vegetable fibre may be taken at 60 *kilogrammes* per circular section of 1 centimetre in diameter, or 76 *kil.* per square centimetre of section, or, finally, at 750 or 800 *times* its weight per running metre.*

These data, we repeat, refer to ropes that are properly tarred; that is to say, not containing more than 20°/₀ of tar. In downcast shafts, and where guides are used, the quantities given above may be exceeded a little, whilst they are rather too high for upcast shafts, or shafts where kibbles are used, because the ropes are then exposed to bad air and accidental shocks.

There is little difference between hemp and aloe-fibre, although the latter is somewhat stronger weight for weight, if not bulk for

* Two formulæ for hemp ropes often quoted in English works are:

$W=C^2\times{\cdot}26$, and $B=C^2\times{\cdot}2$, where
W = weight of rope in lbs. per fathom,
C = circumference in inches,
B = breaking weight in tons.

From these formulæ it would appear that the working load of a hemp rope, if taken at one-fifth of the breaking weight, would be 345 times its weight per fathom. We find by calculation, from the data given by some of the English ropemakers, that the working load of a hemp rope varies from 270 to 330 times its weight per fathom.

The ultimate strength of hemp ropes is also sometimes given at 6,400 lbs. per square inch of sectional area.

bulk. Besides, when aloe-fibre has been tarred in the state of yarn, which ought always to be done when it is intended for mine ropes, it resists hot and damp air better than hemp. Indeed, it is gradually coming more into use at the expense of hemp, which some ropemakers have already ceased to use altogether.

In the case of iron wire ropes it is impossible to lay down a formula expressing the connection between the *sectional area* and the *load;* because the amount of empty space in the section varies according to the gauge of the wire employed, and the size of the core or heart of tarred hemp, which is placed in the axis of each strand, and even in that of the rope. The object of the core is to preserve from oxidation, as far as possible, those parts which cannot be reached with the brush when the rope is being tarred or oiled whilst it is in use.

It is well known that the strength of iron wires per unit of section increases with the fineness of the wire, and it seems therefore as if we ought to employ the finest wire that can be made; but, on the other hand, this very fine wire offers too much surface for oxidation, and it is too easily cut through if it happens to be accidentally chafed. Experience has shown that it is advisable to employ a medium-sized wire between Nos. 12 and 17 of the Paris wire gauge, *i.e.* from 1·8 to 3 millimetres in diameter (0·071 to 0·118 inches, or about No. 15 to No. 11 of the Birmingham wire gauge).

The make of a wire rope is expressed by saying that it is composed of *so many* strands, each consisting of *so many* wires, of *such and such* a gauge; in the case of a flat rope we say it is composed of *so many* round ropes of *such and such* a make.

An average round rope is frequently composed of six strands, and each strand of six wires. In large ropes the strands are made up of more wires.

As the nature of a wire rope is thus defined by the number and size of the wires, it is easy, if we know the section and weight per metre of the gauge employed, to determine the *useful section* of the rope, and its weight per metre.

Admitting as a basis an average breaking strain of 55 kil. per square millimetre (78,228 lbs. per square inch), the Nos. 12 to 17

(Paris wire gauge), employed in making wire ropes, give the results contained in the following table: *

No.	Diameter in tenths of millimetres.	Sectional area in square millimetres.	Weight per metre in grammes.	Breaking strain of the wire in kilogrammes.
12	18	2·545	19·84	140
13	20	3·142	24·48	173
14	22	3·801	29·64	209
15	24	4·524	35·28	249
16	27	5·725	44·63	315
17	30	7·068	55·13	389

According to this table the useful section of a rope composed of six strands, each containing six No. 15 wires, will be $36 \times 4·524 = 1629$ square millimetres, or, roughly speaking, 16 square centimetres.

Its weight per metre will be $36 \times 35·28 = 1270$ grammes, and the breaking strain $36 \times 249 = 8964$ kilogrammes.

As the above table is made out on the assumption that the breaking strain is proportional to the *sectional area*, and consequently to the *weight per metre*, we may infer that the general relation between the breaking strain and the useful weight per running metre is expressed by the ratio $\frac{Q}{P} = \frac{8964}{1·27} = 7058$.

In round numbers it is usual to adopt the ratio $\frac{Q}{P} = 7000$, P being the actual weight of the rope per metre; and in this way we allow, insufficiently it is true, for the core of hemp and tar, and for the shortening due to the twist.

It is well to adopt a somewhat smaller factor of safety for iron wire than for hemp, in order to allow for a greater chance of lack

* Taking the numbers of the Birmingham wire gauge, and assuming a breaking strain of 78,228 lbs. per square inch, and the weight of a cubic foot of wrought iron to be 481 lbs., the table would become:

No. B.W.G.	Diameter in inches.	Sectional area in square inches.	Weight per fathom in lbs.	Breaking strain of the wire in lbs.
11	·120	·01131	·2266	884
12	·109	·00933	·1870	730
13	·095	·00708	·1419	554
14	·083	·00541	·1084	423
15	·702	·00407	·0815	318

of uniformity in the quality, or for some defect of manufacture, which becomes all the more marked as the number of wires decreases.

If this factor is taken from $\frac{1}{6}$ to $\frac{1}{7}$,* we infer that the ratio $\frac{Q'}{P}$ is included between 1,000 and 1,167, or, in round numbers, between 1,000 and 1,200 (or 550 to 650 if we reckon by fathoms instead of metres). We may add that if we replace the iron wire by steel wire of a *thoroughly reliable nature,* the ratio $\frac{Q'}{P}$ may even be put at 1,500 (820 in reckoning by fathoms). This last number, however, is not yet thoroughly adopted in practice.

(449) If we compare the most favourable results for ropes made of vegetable fibre $\left(\frac{Q'}{P}=800\right)$ with the most moderate that we have just determined for wire ropes $\left(\frac{Q'}{P}=1000\right)$, we may sum up what has been said about the materials as follows:

1. As wire ropes are not affected like ropes of vegetable fibre, by hot and bad air, they may last much longer than these, especially in upcast shafts. On the other hand, they may be acted on by acid mine water, and are consequently, to a certain extent, unfitted for use in a pumping shaft unless they are kept very carefully tarred.

2. By using wire ropes we may economize 20% at least of the weight of the vegetable fibre rope that would be necessary *for a given load.* This economy becomes all the more marked, when we come to determine the real load on the rope at the pulley-frame, by adding the weight of the rope itself to the weight of the load attached to one *end* of it.

The advantages of less weight and increased durability may serve as a measure of the pecuniary economy, because nowadays there is little difference of price between the different kinds of ropes. Besides, the price of hemp and aloe fibre will probably

* Many persons prefer to adopt a still smaller factor of safety, especially for quick winding, and take the working load as $\frac{1}{10}$ of the ultimate strength or breaking strain.—*Translators.*

increase more rapidly than that of iron wire, which may even diminish. This circumstance will undoubtedly contribute to a more and more general use of wire ropes.

The objection is made against them, and this is the only one of any consequence, that they do not show signs of wear so plainly as ropes made of vegetable fibre—that they may be sound outside whilst the inside wires are more or less oxidised. This is expressed by the saying, *that they are liable to break without warning.*

To guard against this defect it is advisable to make wire ropes with a core of tarred hemp, to pass them, when made, through a bath of boiling tar, and frequently to pay them over with hot tar with a brush while they are in use.

If these precautions are adopted, and if suitable safety-catches are employed to prevent the consequences of an unexpected breakage, our opinion is that wire ropes are preferable to those made of vegetable fibre, and that if the latter still continue to be used in some districts it is simply in consequence of a habit which has little to justify it, or because they can be more easily procured in the locality.

In addition to ropes, iron chains are also employed, although less frequently. They coil round small drums better, they resist friction better, and they last considerably longer; but, on the other hand, they are very much heavier than wire ropes. The reason of this is that, in the first place, iron in bars has a smaller breaking strain than iron in wire; and, secondly, the ultimate strength of a chain is usually taken at only 1½ times that of the bars used in making the links, so as to allow for any defect in welding, or an unequal distribution of the load between the two sides of the link when the chain is bent. Consequently, if we allow 50,000 to 51,000 lbs. per square inch (35 to 36 kilos. per square millimetre) for the ultimate strength, instead of 78,000 lbs. (55 kilos.), the amount laid down for iron wire, and if we suppose that it is desirable to adopt the same factor of safety in both cases, we naturally conclude that the bars of iron *employed in making the chain* ought to be *just as heavy per fathom* as a wire rope with an equivalent breaking strain.

The *weight of a chain* per fathom varies according to the shape

of the links. With very long links (fig. 333 A) there is rather more than double the weight per fathom of the bars of iron employed. If the links are made as short as possible (fig. 333 B), it is evident that, if d denotes the diameter of the iron rod employed, the total length of a link is equal to $4d$, and that the length of iron required to made such a link is $2(d+2\pi d)$; the weight of the chain would bear the same proportion to the weight of the rope as $2(d+2\pi d)$ to $4d$, and the load referred to the weight per metre or fathom would be in the inverse ratio, $\frac{4d}{2(d+2\pi d)}=\frac{2}{1+2\pi}$, or in round numbers $\frac{2}{7}$.

If, then, in the case of wire ropes we admit $Q'=1000$ to 1,200 P, we should have values in the case of chains varying, according to the length of the links, from a maximum $Q'=500$ to 600 P (273 to 328 in reckoning by fathoms) to a minimum $Q=286$ to 343 P (156 to 187 in reckoning by fathoms).

The value $Q'=400$ P (218 for fathoms) is admitted without objection; in other words, a chain has to be made 2½ to 3 times as heavy as a wire rope which will support the same load.

The use of chains is gradually dying out; their excessive weight is a great inconvenience, which increases with the depth. It may also be fairly doubted whether it is reasonable to use a chain, inasmuch as a transmitting medium made up of *so large a number of separate parts* is inferior, from a mechanical point of view, to a rope composed of *a number of longitudinal elements*, which are united so as to cause the strain to be distributed equally.

(450) We may remark in the formulæ for the breaking or working loads as functions of the weight per metre, that the coefficient of the weight is the length of rope in metres, which would break from the sole effect of its own weight, or at all events reach the practical limit of load, if suspended freely by one end, and without any additional weight attached to it.

It is evident that, in dealing with the working load, these lengths are not very far removed from the depths already attained by certain mines, and in the case of hemp and aloe-fibre ropes they are less than those depths. Two conclusions may be drawn from

this. Firstly, in *tolerably deep* mines the weight of the rope, supposed to be of uniform section, may become a very considerable fraction of the load it bears at the pulley-frame when the whole of it is hanging down the pit; secondly, in *very deep mines* the mere weight of the rope alone may cause it to be *overloaded.*

A further result is that the amount of resistance to be overcome whilst a cage or kibble is being drawn up varies considerably; for, in starting, the rope which hangs down the pit, and *has to be raised,* is a resistance, but on the cage reaching the surface the other rope, which has been unwound, is acting as a power.

Suppose, for instance, to take a case in point, a pit 400 metres (437 yards) deep, in which we wish to raise 1,600 kil. (31 cwt.) of useful load, and 2,000 kil. (39 cwt.) of dead weight, or in all 3,600 kil. ($3\frac{1}{2}$ tons).

We will further suppose that the rope is made of aloe-fibre, satisfying the formula $Q' = 800$ P (437 in reckoning by fathoms).

If we denote by x the weight of this rope per metre we shall begin by laying down the equation

$$3600 + 400x = 800x.$$

$$x = \frac{3600}{400} = 9 \text{ kil. (36 lbs. per fathom.)*}$$

As the dead weights balance each other, the load on the engine at starting will be:

$$1600 + 400 \times 9 = 1600 + 3600 = 5200 \text{ kil. (5 tons).}$$

When the cage reaches the surface the load will be:

$$1600 - 3600 = -2000 \text{ kil. } (-39 \text{ cwt}).$$

Thus on starting the total load would have been more than three times that of the useful load, and yet it would be necessary to shut off steam, and use the break or counter-pressure of steam during the last part of the ascent.

If iron wire rope is used, for which $Q' = 1000$ P, we shall find, by pursuing the same line of reasoning,

$$3600 + 400x = 1000x.$$

$$x = \frac{3600}{600} = 6 \text{ kil. (24 lbs. per fathom.)}$$

* The weight in kilogrammes per metre multiplied by 4 gives the weight in pounds per fathom.

The weight of the rope per metre is, therefore, 6 kil.; and the loads on the engine, at starting and on arrival, are determined by the relations

$$1600 + 400 \times 6 = 1600 + 2400 = 4000 \text{ (3 tons 18 cwt.)}$$
$$1600 - 400 \times 6 = 1600 - 2400 = -800 \text{ (} -15 \text{ cwt.)}$$

Thus the wire rope is lighter than the rope made of vegetable fibre, and causes the resistance to be more regular, or rather *less irregular.*

The above example demonstrates the fact, that even at a depth of 400 metres (437 yards) the weight of the rope is a matter of considerable consequence; and it will become of more consequence as the depth goes on increasing. The advantage of using a wire rope, therefore, becomes more and more marked, until a depth is reached of 700 or 800 metres (say 750 to 900 yards), when no other kind of rope can be used.

(451) We have just seen that if ordinary ropes are used, it is necessary to increase their strength with an increasing depth; and further, that the increased length and strength of the rope create additional irregularity in the resistance which the engine has to overcome. Attempts have been made to prevent, or at all events to diminish, these inconveniences by two methods, which we must now describe.

In order to render ropes available for winding at increased depths the *tapering* form has been adopted; that is to say, the ropes, instead of being of the same size throughout, are made with a sectional area increasing from below upwards, so that at any given point they are merely strong enough to sustain with safety the total strain at that point, *i.e.* the weight hanging at the end of the rope + the total weight of the rope itself below the point under consideration.

Let us denote by a (fig. 334) the sectional area of the rope at the small end, R the load hanging to it, A the sectional area at any given point, P′ the weight per metre of a rope with a sectional area equal to the unit of surface, or, in other words, the weight of a cubic metre of the rope in question, P the working load per unit of sectional area.

It is evident that the weight of a piece of rope of the length dh will be expressed by the formula $P'Adh$.

The working load of the rope in passing from the sectional area A to the sectional area $A+dA$ is increased by PdA.

We must lay down the equation $P'Adh = PdA$; from which we infer

$$\frac{P'}{P}dh = \frac{dA}{A} \quad . \quad . \quad . \quad \frac{P'}{P}h = \log. A + C.$$

We can determine the constant from the fact that when $h = O$, we get $A = a$.

Then $\frac{P'}{P}h = \log. \frac{A}{a} \ . \ . \ . \ A = ae^{\frac{P'}{P}h}$; and, therefore, denoting by A_1 the sectional area at the top, $A_1 = ae^{\frac{P'}{P}H}$.

On the other hand, $\frac{P}{P'} = \mu$ is the weight which a rope of the size under consideration can carry when it weighs one kilogramme per metre (it is the quantity expressed above, in Nos. 448 and 449, by $\frac{Q'}{P}$, or 750 for hemp, 800 for aloe-fibre, 1000 for iron wire, 1500 for steel wire).

As we have also $R = Pa$, we obtain finally the formula $A_1 = \frac{R}{P}e^{\frac{H}{\mu}}$, which will give the sectional area of the tapering rope at the distance H from the bottom when we know the load R and the constants P and μ for the special kind of rope under consideration.

The total weight of the rope is given by the formula:

$$Q = \int_0^H P'Adh = \int_a^A PdA = P(A_1 - a) = R\left(e^{\frac{H}{\mu}} - 1\right).$$

The weight per metre at the small end is equal to:

$$P'a = Pa \times \frac{P'}{P} = \frac{R}{\mu}$$

and the weight at the large end will be:

$$P'A_1 = R\frac{P'}{P}e^{\frac{H}{\mu}} = \frac{R}{\mu}e^{\frac{H}{\mu}}.$$

The formula for the total weight of a tapering rope $Q = R\left(e^{\frac{H}{\mu}} - 1\right)$ should be compared with that of ropes of uniform section; using the same notation, this weight, as we saw in the preceding paragraph, is given by the general formula:

$$R + Hx = \mu x \quad . \quad . \quad . \quad x = \frac{R}{\mu - H}$$

consequently

$$Hx = \frac{RH}{\mu - H} = \frac{R\frac{H}{\mu}}{1 - \frac{H}{\mu}}.$$

These two general values:

$$Q = R\left(e^{\frac{H}{\mu}} - 1\right) \text{ for the tapering rope,}$$

$$Q = R\frac{\frac{H}{\mu}}{1 - \frac{H}{\mu}} \text{ for the rope of uniform section,}$$

both give a weight of nothing, when $H = 0$, which is as it ought to be; but for $H = \mu$ the second gives an infinite value. This indicates, as already stated, the impossibility of sustaining any load by a rope which has reached this limit of length; whilst the first formula gives $Q = R(e - 1)$, a finite quantity to which there is no objection, and which does not become infinite till H is infinite.

Thus *theory* shows that the depths to which ropes of uniform section can be used are *necessarily limited;* whereas there is *no limit* with ropes tapering properly.

This difference is of primary importance, and deserves serious consideration, as mines approach depths where it is evidently impossible to use ropes of uniform section.

In practice the size is not diminished continuously, according to the exponential formula deduced above, but at intervals, by leaving out, for instance, one wire in each strand. Care is of course taken to make sure by direct calculation that, even when so diminished, the rope is at any given point sufficiently strong to bear the total load at that point.

(452) We see, therefore, that tapering ropes enable us to wind from greatly increased depths. They are much lighter than ropes of *uniform section,* because if the section is uniform it must be *greater* than the greatest section of a tapering rope. With tapering ropes, therefore, we obtain *a smaller difference* between the initial load and the final load on the engine; but even then the difference is still considerable, and the rate of variation increases more rapidly, because the weight per unit of length of the rope that is being wound up is decreasing, and that of the other rope increasing, during a journey of the cages. We must therefore have recourse to other means for equalizing the load, at all events to some extent. This question is of considerable practical importance, for enabling one not only to work the engine easily, but also to reduce the power required, which has to be amply sufficient to overcome the greatest amount of strain put upon the machinery.

At first sight it might be thought that one of the means of effecting this object would be to employ the variable expansion to which we have already alluded. This would be enough, if we merely wished to render the speed of the engine regular; by handling the gear for variable expansion in a proper manner it is possible to attain a practically uniform velocity. But this would not prevent irregularity *in the work done during each revolution of the engine.* Now, it is this irregularity that ought to be eradicated if we wish to derive all possible advantage from the use of expansion. The result would evidently still be inadequate, if the equalization of the speed obliged us to work during part of the time at a low rate of expansion.

What is wanted in practice is a *high degree of expansion,* so as to effect *economy of coal.* Now, a high rate of expansion cannot be maintained uniformly whilst a cage is being drawn up at an almost uniform velocity, unless *the dynamical equilibrium* (*Cours de Machines* No. 13) is fairly sustained between the different forces acting on the engine.

We must, therefore, effect the equalization by some other means than variable expansion. For *round ropes on cylindrical drums* we may employ either the endless rope system or counterpoises, both of which afford a *strict* solution of the problem. For *flat ropes on*

reels or round ropes on conical drums, we may calculate a mean radius which solves the problem in an approximate manner only, but at the same time we may correct its effect by using a counterpoise also.

The endless rope is occasionally used with water-balances. The two ends of a rope, or more often a chain, are attached under the tanks which receive the water that constitutes the motive power. The chain is made just so much longer than the depth of the shaft as is necessary to enable it to pass round a return pulley at the bottom. If the main chain, and the counterpoise chain are equally heavy per unit of length, the whole system is in equilibrium in all positions as far as the chains and tanks are concerned; the water contained in one tank has merely to overcome the weight of the useful load placed on a platform on the top of the other.

This arrangement is perfectly practicable, and is indeed in actual use, but only for comparatively insignificant depths. The same system has been proposed with steam as a motive power; but it has not been used, and it does not seem advisable to employ it.*

Proposals have been made, and indeed the arrangement has been carried out in some mines, to use endless chains moving constantly in one direction, and acting in the same way as certain elevators or hoists for blast furnaces, or like Jacob's-ladders or chain-pumps.

This system ought to be absolutely condemned in all mines of any depth; for it requires heavy and complicated apparatus, and a multitude of joints, and if one of these gives way it may cause a breakage attended with the gravest consequences.

(453) The counterpoise system, which on the contrary is both practical and in actual use, consists in having a heavy chain moving up and down in one of the compartments of the winding pit. It is worked by a special rope passing over a drum on the same shaft as the regular winding drum.

* Since the above was written the endless rope system has been applied successfully at a number of collieries both in this country and on the Continent.—*Translators.*

We will suppose that we are dealing with a case where a round rope is coiled upon a cylindrical or slightly conical drum, like that of figure 329. The arrangement is that the special counterpoise rope shall be wound up to its maximum *at the beginning* of an operation, that it shall be completely unwound when the same operation is half completed, and again wound up to a maximum at the end of the same operation, but in the opposite direction. At the commencement the chain is entirely supported by the rope, and acts as a *power;* at the meeting point of the cages or kibbles all the chain is lying on a platform at the bottom of the special compartment provided for it, or it is hanging from a fixed point in the middle of the compartment; and after this it is gradually lifted up again, and exerts an increasing resistance until the end of the operation. All its weight is then acting *as resistance,* and it has taken up the proper position for acting *as a power,* when the motion is reversed in the next operation of winding.

Suppose, for instance, that the chain is fixed to the middle of the compartment (fig. 335), and that its length is equal to half the depth. Let us denote by H the total depth of the pit, and by h that of the compartment containing the chain counterpoise.

Let P be the weight per unit of length of the winding ropes coiled upon a drum of radius R, and P′ the weight per unit of length of the chain counterpoise, suspended to a rope the weight of which we neglect, and which is wound upon a drum of radius r.

We have first of all the relation

$$\frac{R}{r} = \frac{H}{2h},$$

because the rope of the counterpoise traverses twice the length of the compartment during one ascent of the cage.

We then have the equation of the moments $P'\frac{h}{2} \times r = PH \times R,$

which expresses the fact that the chain and winding rope balance each other when the cage starts from the bottom, and when it arrives at the top; consequently they are also in equilibrium in all intermediate positions, for their effects vary in the same proportion to the space described.

The second equation may be written

$$\frac{P'h}{2} = PH \times \frac{R}{r} = PH\frac{H}{2h}.$$

Thus the total weight of the chain counterpoise is to the total weight of one of the ropes, as the depth of the pit is to twice the depth of the compartment.

The solution of the problem is just as easy if the chain, instead of being fastened in the middle of the compartment, is allowed to lie on the bottom of it. In this case the chain must be as long as the compartment. It is evident that the first equation would remain the same, and the second would become

$$P'h = PH \times \frac{H}{2h}.$$

In other words, the chain would have the same total weight, and consequently the weight per unit of length would be half what it was in the first case.

As the *total weight* of these chains varies in the inverse ratio of their length, and consequently *their weight per unit of length* in the inverse ratio of the squares of their lengths, they cannot be fixed without some inconvenience in a compartment of a winding shaft, where serious damage might be caused if they were to break accidentally; though breakages are easily prevented by proper attention. In many cases a small shaft, or *staple*, is sunk specially for the purpose of receiving the chain counterpoise, and it is advisable that the engine should be between it and the winding pit, so as to reduce the strain on the journals of the drum-shaft.

It was a common plan formerly, especially in the north of England, to use, instead of the chain counterpoise, a small but heavily laden waggon running on a short line of rails. (Fig. 336.) The line is constructed with a very steep gradient at the top, but gradually reduced to nothing at the bottom. During one winding operation the waggon travels over the road twice, once down and once up. The pull which it exerts on the rope is at its maximum at starting, it is nothing at the meeting place, and at the end it is again at its maximum. This waggon, like the chain, acts as a

power on starting, and as a resistance when the cage reaches the surface; and then once more as a power when the motion is reversed for the next operation. It is evident that with a properly constructed curve the same result may be attained as with the chain counterpoise, and perhaps in a more practical manner, and at less expense in difficult ground, than by sinking a special shaft.

(454) Let us now finally consider the last means pointed out in No. 452; viz., that of using flat ropes and drums to correspond (*reels*).

It is easy to see that this system affords a certain amount of equalization; for the radius of the coil of the ascending rope goes on increasing, and that of the descending coil is always diminishing; consequently in proportion as the *resistance* diminishes and the power *increases*, the leverage of the first *increases*, and that of the latter *decreases*.

The variation in the length of leverage for each revolution is a constant quantity, or one varying very slightly, equal to the thickness of the rope where it is wound on the drum; and consequently the proportional variation increases with the smallness of the actual radius of the coil, and diminishes as this grows larger.

We perceive, in a general way, that the effects produced must depend upon the size of the mean radius of the coil. This mean is the radius of the coil when the two cages meet; because, starting from this point, it is necessary that the same number of revolutions one way or the other should bring one of the cages to the surface, and the other to the hooking-on place at the same moment.

The result is that the cages do not meet *in the middle of the pit*, but *in the middle of the total number of revolutions* that the drum has to make for a complete operation. It is easy to infer that this meeting takes place *below* the middle of the pit; for the first revolutions make the empty cage travel through a greater space, and the full cage through a smaller space than the last revolutions.

Having laid down these preliminaries, we will denote the fixed data of the problem as follows:

Q the useful load suspended to the ascending rope;

q the dead weight suspended to each of the ropes;

H the total depth of the shaft, or the distance between the surface and the onsetting place (*plat*);

$S > \frac{H}{2}$ the depth of the meeting place;

p the weight of the rope per unit of length;

e its thickness. (With a rope of uniform section these two elements p and e are constant; their mean values would be taken in the case of a tapering rope.)

ρ the mean radius of the coil, which is the same on both drums when the two cages meet;

n the number of revolutions necessary to bring the cages from their starting points to the meeting place, or from the meeting place to their destinations;

ω the constant angular velocity of the drum-shaft.

We will further denote the variable elements which correspond to a given position of the cage by the following letters:

σ and σ' the spaces traversed simultaneously from the meeting-place, the former by the ascending, the latter by the descending cage. We have $\sigma > \sigma'$;

a the corresponding angle described by the drum-shaft;

m the number of revolutions corresponding to the angle a, which gives the relation $a = m\ 2\pi$;

z and z' the radii of the coils of the ascending and descending ropes;

M the moment of the forces acting on the drum-shaft.

At each revolution of the shaft the radius z is increased by the quantity e.

When an angle a has been described we shall have:

$$z = \rho + e\frac{a}{2\pi} \quad . \quad . \quad . \quad dz = e\frac{da}{2\pi}, \quad . \quad . \quad . \quad \frac{dz}{da} = \frac{e}{2\pi}.$$

Besides, we have in a general way:

$$d\sigma = \sqrt{dz^2 + z^2 da^2}.$$

This equation may be written:

$$d\sigma = z da \sqrt{1 + \left(\frac{e}{2\pi z}\right)^2};$$

or, neglecting the term $\left(\frac{e}{2\pi z}\right)^2$, which comes to the same thing as taking the spiral arc formed by one revolution of the rope as a circumference:

$$d\sigma = zda = \left(\rho + e\frac{a}{2\pi}\right) da;$$

from which we deduce:

$$\sigma = \rho a + e\frac{a^2}{2\pi} = 2\pi\left(m\rho + e\frac{m^2}{2}\right),$$

remarking that the constant introduced by the integration is *nil*, because we ought to have $\sigma = 0$ when a or m are nothing.

We shall find by repeating the same calculations:

$$\sigma' = 2\pi\left(m\rho - e\frac{m^2}{2}\right),$$

and consequently $\sigma + \sigma' = 2 \times 2\pi m\rho$; that is to say, that the *relative velocity* of the two cages is constant, because the space described in virtue of this velocity is proportional to the number of revolutions.

If we make $m = n$, we shall have:

$$\sigma + \sigma' = \mathrm{H} = 4\pi n\rho \quad . \quad . \quad . \quad n = \frac{\mathrm{H}}{4\pi\rho}.$$

This equation gives the number n when we know the depth of the pit H, and the mean radius ρ of the coil.

It must be understood that though the *distance between the two cages increases by a uniform motion*, each cage itself has *a varying motion*, the acceleration of which is positive for the ascending and negative for the descending cage. These accelerations can be calculated if we know the velocities as functions of the time.

These velocities are $(\rho \pm me)\,\omega$, and their differential with reference to the time is $\pm\, e\omega\frac{dm}{dt}$.

As we have also $m \times 2\pi = \omega t$, we deduce $\frac{dm}{dt} = \frac{\omega}{2\pi}$, and the acceleration is $\pm\, e\frac{\omega^2}{2\pi}$.

The strain on the end of the ascending rope is therefore

$$(\mathrm{Q} - q)\left(1 + \frac{e\omega^2}{2\pi g}\right),$$

and that of the descending rope

$$q\left(1-\frac{e\omega^2}{2\pi g}\right).$$

As the term $\frac{e\omega^2}{2\pi g}$ may be neglected, the strains on the ropes during the winding are practically the same as when they are in a state of rest.

This may be seen also by figures. Suppose, for instance, $e = 0^m{\cdot}03$ (1·18 inch), $\omega = 0^m{\cdot}05$ (2 inches), which corresponds to a velocity of about ten revolutions a minute; and knowing that $\pi = 3{\cdot}14$, and $g = 9{\cdot}81$, then we find that $\frac{e\omega^2}{2\pi g} = 0{\cdot}00049$; that is to say, that the action of gravity is only altered by a few ten-thousandths.

We shall therefore put down for the moment of the loaded rope which is ascending

$$(Q+q)\,(\rho+me)+\left[p\mathrm{S}-p2\pi\left(m\rho+\frac{em^2}{2}\right)\right](\rho+me),$$

and for the moment of the rope which is descending empty

$$q\,(\rho-me)+\left[p\mathrm{S}+p2\pi\left(m\rho-\frac{em^2}{2}\right)\right](\rho-me);$$

and their difference, which represents the moment which the engine has to overcome, is, after making all reductions,

$$\mathrm{M} = Q\rho + (Q + 2q + 2p\mathrm{S})\,em - 4p\pi\rho^2 m - 2p\pi e^2 m^3.$$

At the meeting-place—that is to say, when $m = 0$—the formula shows that the moment is simply $Q\rho$, which is evident, because then the two ropes and the two dead weights balance each other.

The variations of the moment about this mean value are therefore

$$\mathrm{M} - Q\rho = (Q + 2q + 2p\mathrm{S})\,em - 4p\pi\rho^2 m - 2p\pi e^2 m^3.$$

In this equation m may vary from $-n$ at the starting of the cages, to $+n$ on their arrival.

We shall eliminate S, which is not an explicit datum of the problem, remarking that we have

$$\mathrm{S} = 2\pi\left(n\rho+\frac{en^2}{2}\right),$$

and as $n = \frac{H}{4\pi\rho}$, we get

$$S = \frac{H}{2} + \frac{H^2 e}{16\pi\rho^2}.$$

This verifies the conclusion, at which we had arrived *à priori*, that the meeting-place is *below* the middle of the shaft.

Substituting this value of S, we get finally:

$$M - Q\rho = \left[(Q + 2q + pH)\, e + \frac{pH^2e^2}{8\pi\rho^2} - 4p\pi\rho^2\right] m - 2p\pi e^2 m^3 \; . \; . \; . \; (2)$$

455. The above equation may be represented by a curve taking $M - Q\rho$ as ordinate, and m as abscissa. It represents a curve of he third degree, and contains only uneven powers of the abscissa. It passes through the origin of the co-ordinates, because we have $M - Q\rho = 0$ when $m = 0$; and this origin is a centre of the curve, because with the two conjugate values $+m$ and $-m$, the ordinate only changes its sign, but still retains its absolute value.

We may propose to satisfy various conditions by means of this curve, the general form of which is shown in figure 337.

If, for instance, we wish to have $M - Q\rho = 0$ at the beginning and end of an operation, as it is in the middle, it is necessary that the second member be reduced to zero when $m = \pm n$ (fig. 338).

We write down, therefore,

$$0 = (Q + 2q + pH)\, e + \frac{pH^2e^2}{8\pi\rho^2} - 4p\pi\rho^2 - 2p\pi e^2 n^2,$$

and we then replace n by its value $\frac{H}{4\pi\rho}$.

It is easy to see that, by making this substitution, the fourth term of the second member cancels the last, and the equation becomes simply:

$$0 = (Q + 2q + pH)\, e - 4p\pi\rho^2$$

$$\rho^2 = \frac{(Q + 2q + pH)\, e}{4p\pi} \; . \; . \; . \; \rho = \frac{1}{2}\sqrt{\frac{(Q + 2q + pH)\, e}{p\pi}} \; . \; . \; . \; (3)$$

This then is the value of the radius ρ, which enables us to satisfy the above condition of having the same moment *at the two ends and in the middle of an operation.*

We denote this first value by ρ_0.

It will be remarked that with this value the coefficient of the term in m in equation (2) is positive, or that $\frac{d(\mathrm{M}-\mathrm{Q}\rho)}{dm}$ is positive when $m=0$. The curve therefore has the form shown in figure 338.

Although this value of ρ_0 is tolerably satisfactory, it is not the most favourable which can be selected.

We can keep nearer the axis of the abscissæ on an average—or, in other words, the quantity $\mathrm{M}-\mathrm{Q}\rho$ will have smaller values—if we assume the condition that this quantity shall be reduced to nothing for a certain value m smaller than n, and that the value AA′ which corresponds to the point A (fig. 339) shall be equal but contrary in sign to the maximum value CC′, which the ordinate has taken between the points O and B. This result, obtained on the side of the positive abscissæ, will hold good on account of symmetry on the side of the negative abscissæ.

We wish therefore that $\mathrm{M}-\mathrm{Q}\rho$ should be reduced to zero for a certain value $m=\frac{n}{x}$, x being greater than 1.

We lay down the equation:

$$(\mathrm{Q}+2q+p\mathrm{H})\,e+\frac{p\mathrm{H}^2e^2}{8\pi\rho^2}-4p\pi\rho^2=2\rho\pi e^2\frac{n^2}{x^2},$$

and we deduce from this the general value:

$$\mathrm{M}-\mathrm{Q}\rho=2p\pi e^2\left(\frac{n^2}{x^2}m-m^3\right). \qquad (4)$$

The maximum of this function, with reference to the variables m, will be obtained by making its differential equal to zero. We infer from this:

$$\frac{d(\mathrm{M}-\mathrm{Q}\rho)}{dm}=2p\pi e^2\left(\frac{n^2}{x^2}-3m^2\right)=0;$$

therefore

$$m^2=\frac{n^2}{3x^2}\quad .\;.\;.\quad m=\frac{n}{x\sqrt{3}}\quad .\;.\;.\quad \mathrm{OB}=\mathrm{OC}\sqrt{3}.$$

Thus there is a definite ratio between the abscissa which corresponds to the maximum and the abscissa whose ordinate is zero.

If we now replace m in the above equation by the special value $m=\frac{n}{x\sqrt{3}}$, the result ought to be zero, and in fact we have identically

$\frac{n^2}{x^2}=3\frac{n^2}{3x^2}$. But we wish also, when $m=n=\text{OA}$, to have the same value, excepting the sign, as if we take $\text{OC}=\frac{n}{x\sqrt{3}}$. This comes to the same thing as laying down the equation:

$$-\left(\frac{n^2}{x^2}n-n^3\right)=\frac{n^2}{x^2}\frac{n}{x\sqrt{3}}-\frac{n^3}{3x^3\sqrt{3}};$$

or dividing by n^3,

$$1-\frac{1}{x^2}=\frac{1}{x^3\sqrt{3}}-\frac{1}{3x^3\sqrt{3}}=\frac{2}{3x^3\sqrt{3}},$$

and arranging this with reference to x,

$$x^3-x-\frac{2}{3\sqrt{3}}=0. \qquad (5)$$

As this equation is of an odd degree, and has its last term negative *with an uneven number of positive roots,* and as it has only one variation, it has *only one positive root.* This root solves the problem.

To obtain this root we remark that the equation has the form $x^3+px+q=0$.

Its three roots are given algebraically, one by the formula:

$$x'\sqrt[3]{-\frac{1}{2}q+\sqrt{\frac{1}{27}p^3+\frac{1}{4}q^2}}+\sqrt[3]{-\frac{1}{2}q-\frac{1}{2}\sqrt{\frac{1}{27}p^3+\frac{1}{4}q^2}};$$

the other two by the formula:

$$x=\frac{-1\pm\sqrt{-3}}{2}\sqrt[3]{-\frac{1}{2}q\pm\sqrt{\frac{1}{27}p^3+\frac{1}{4}q^2}}.$$

We have also

$$-\frac{1}{2}q=\frac{1}{3\sqrt{3}}$$
$$\frac{1}{27}p^3=-\frac{1}{27}$$
$$\frac{1}{4}q^2=\frac{1}{27}.$$

The positive root is

$$2\sqrt{\frac{1}{3\sqrt{3}}}=\frac{2}{\sqrt{3}},$$

and the two others are imaginary on account of the term $\sqrt{-3}$.

We have therefore

$$OB = \frac{n}{x} = n\frac{\sqrt{3}}{2}, \text{ and } OC = \frac{OB}{\sqrt{3}} = \frac{n}{2}.$$

Thus, as the quantity n is represented by OA, we have $OB = \frac{OA\sqrt{3}}{2}$, and $OC = \frac{OA}{2}$.

The maximum value and the final value, which is equal to it and of opposite sign, are obtained by taking equation (4), and substituting for $\frac{1}{x^2}$ its value $\frac{3}{4}$, and then making $m = \frac{n}{2}$ for the first and $m = n$ for the second.

We thus obtain:

$$\text{For } m = \frac{n}{2}, \ M - Q\rho = 2p\pi n^3 e^2\left(\frac{3}{4} \times \frac{1}{2} - \frac{1}{8}\right) = \frac{p\pi n^3 e^2}{2}$$

$$\text{For } m = n, \ M - Q\rho = 2p\pi n^3 e^2\left(\frac{3}{4} - 1\right) = -\frac{p\pi n^3 e^2}{2},$$

and these two values are, as they ought to be, equal and of opposite signs.

Substituting for n^3 its value $\frac{H^3}{64\pi^3\rho^3}$, we get

$$M - Q\rho = \pm\frac{1}{128}\frac{pe^2H^3}{\pi^2\rho^3},$$

and, lastly, the value of the proportional increase of interval will be:

$$\frac{M - Q\rho}{Q\rho} = \pm\frac{1}{128}\frac{pe^2H^3}{\pi^2 Q\rho^4}.$$

We now have to determine the radius ρ.

For this purpose we once more take up the equation:

$$(Q + 2q + pH)\,e + \frac{pH^2e^2}{8\pi\rho^2} - 4p\pi\rho^2 = 2p\pi e^2\frac{n^2}{x^2},$$

and we substitute in it the values $n^2 = \frac{H^2}{16\pi^2\rho^2}$, and $x^2 = \frac{4}{3}$.

The term of the second member becomes $\frac{3}{32}\frac{pH^2e^2}{\pi\rho^2}$, and by combining it with the fourth of the first member we get:

$$(Q + 2q + pH)\,e + \frac{1}{32}\frac{pH^2e^2}{\pi\rho^2} - 4p\pi\rho^2 = 0\,;$$

or by arranging with reference to ρ, dividing by $4p\pi$, and changing the signs:

$$\rho^4 - \frac{Q+2q+pH}{4p\pi} e\rho^2 - \frac{1}{128}\frac{H^2e^2}{\pi^2} = 0.$$

We deduce from this a value ρ_1^2 given by the relation:

$$\rho_1^2 = \frac{(Q+2q+pH)\,e}{8p\pi} \pm \sqrt{\left[\frac{(Q+2q+pH)\,e}{8p\pi}\right]^2 + \frac{1}{128}\frac{H^2e^2}{\pi^2}},$$

or referring to the value ρ_0 found above, and considering only its real value:

$$\rho_1^2 = \frac{1}{2}\rho_0^2 + \sqrt{\left(\frac{1}{2}\rho_0^2\right)^2 + \frac{1}{128}\frac{H^2e^2}{\pi^2}}.$$

Thus the second value ρ_1 is *a little larger* than the first ρ_0. The term under the root which gives the correction is of very little importance.

Thus, for instance, suppose $H = 400$ metres (437 yards), $e = 0^m{\cdot}03$ (1·18 inch), the term $\frac{1}{128}\frac{H^2e^2}{\pi^2}$ is equal to 0·11.

We will now apply the formula to a numerical example, and in addition to the above values given to H and e, we will take:

$Q = 1600$ kil. (1 ton 11 cwt.)
$q = 2000$ kil. (1 ton 19 cwt.)
$p = 7$ kil. (28 lbs. per fathom.)

We shall have

$$(Q+2q+pH)\,e = 222, \quad 4\,p\pi = 88,$$

and consequently

$$\rho_0^2 = 2{\cdot}52 \;\ldots\; \rho_0 = 1{\cdot}60, \quad n = \frac{H}{4\pi\rho_0} = \text{about 20 revolutions.}$$

$$\rho_0 + ne = 1{\cdot}60 + 0{\cdot}60 = 2^m{\cdot}20 \text{ (7 ft. } 2\tfrac{1}{2}\text{ in.)}$$

$$\rho_0 - ne = 1{\cdot}60 - 0{\cdot}60 = 1^m \text{ (3 ft. } 3\tfrac{1}{2}\text{ in.)}$$

$$\rho_1 = \sqrt{\frac{1}{2}\rho_0^2 + \sqrt{\left(\frac{1}{2}\rho_0^2\right)^2 + 0{\cdot}11}}$$

or approximately

$$\rho_1 = \sqrt{\rho_0^2 + 0{\cdot}06} = \rho_0 + 0{\cdot}03 = 1{\cdot}63.$$

We deduce from this:

$$n = \frac{H}{4\pi\rho_1} = \text{about 19 revolutions.}$$

$$\rho_1 + ne = 1{\cdot}63 + 0{\cdot}57 = 2^{\mathrm{m}}{\cdot}20 \text{ (7 ft. } 2\tfrac{1}{2} \text{ in.)}$$
$$\rho_1 - ne = 1{\cdot}63 - 0{\cdot}57 = 1^{\mathrm{m}}{\cdot}06 \text{ (3 ft. } 5\tfrac{3}{4} \text{ in.)}$$

Thus the mean radius calculated under the second hypothesis is rather greater, and consequently the number of revolutions and the distance between the extreme radii a little less, than under the first hypothesis.

The proportional difference, $\frac{M - Q\rho}{Q\rho}$, becomes under the second hypothesis $\frac{1}{128}\frac{pe^2H^3}{\pi^2 Q\rho_1^4} = 0{\cdot}03$.

We see how small this amount is, especially when compared with the considerable variations calculated in No. 450 for round ropes on cylindrical drums.

(456) The theory set forth in the two preceding paragraphs *ought generally to be applied*, and it is evident from the above calculations that it may lead to numerical values that are perfectly acceptable, and realize a very remarkable degree of uniformity of load.

Two remarks, however, are necessary. The first is, that the above calculations are not very strictly correct with tapering ropes, which increase in value with the depth of the pits, and are even indispensable for very deep mines. The second remark relates to the numerical value of the radii ρ_0 and ρ_1. We must admit that the values $\rho_0 - ne$ and $\rho_1 - ne$ are already somewhat small in the example which has been given, especially because they correspond to the winding up of the large end of the rope, which would require the greatest diameter.

With a given mean radius, this inconvenience will increase with the thickness of the rope, with the amount which is expressed by the quantity $n = \frac{H}{4\pi\rho}$, and with the depth of the pit.

In this case, in order not to strain the rope too much, we must take the value of ρ greater than that furnished by the above calculations, and the quantity $\rho - ne = \rho - \frac{He}{4\pi\rho}$ increases *doubly*, because the first term increases and the second diminishes.

It is easy to see the effect of this on the curve which is the geometrical locus of equation (2) of No. 454, which is—

$$M - Q\rho = \left[(Q + 2q + pH)\, e + \frac{pH^2e^2}{8\pi\rho^2} - 4p\pi\rho^2\right] m - 2p\pi e^2 m^3.$$

If the second member is made equal to 0, we can get the points where $M - Q\rho = 0$. There are three of these points; one is the origin of the co-ordinates, and the others are two points situated symmetrically, and having abscissæ determined by the equation—

$$\left[(Q + 2q + pH)\, e + \frac{pH^2e^2}{8\pi\rho^2} - 4p\pi\rho^2\right] - 2p\pi e^2 m^2 = 0.$$

It is evident that these values of m are not real unless the first term is positive, and that they are reduced to nothing if we lay down

$$(Q + 2q + pH)\, e + \frac{pH^2e^2}{8\pi\rho^2} - 4p\pi\rho^2 = 0.$$

The three points m are blended together at the origin, and the curve is tangent to the axis of the abscissæ and osculatory with it. The form of it is shown in figure 340.

Arranging the above equation with reference to ρ, and dividing by $4p\pi$, we get

$$\rho^4 - \frac{(Q + 2q + pH)\, e}{4p\pi} \rho^2 - \frac{1}{32} \frac{H^2e^2}{\pi^2} = 0,$$

and this equation furnishes only one real value for ρ; viz.,

$$\rho = \sqrt{\frac{(Q + 2q + pH)\, e}{8p\pi} + \sqrt{\left[\frac{(Q + 2q + pH)e}{8p\pi}\right]^2 + \frac{1}{32} \frac{H^2e^2}{\pi^2}}}.$$

If we denote this particular value of ρ by ρ_2, and take into account the value of ρ_0, determined above, we may state the equation

$$\rho_2 = \sqrt{\frac{1}{2}\rho_0^2 + \sqrt{\left(\frac{1}{2}\rho_0^2\right)^2 + \frac{1}{32}\frac{H^2e^2}{\pi^2}}}.$$

This value is evidently greater than ρ_0, and even greater than ρ_1, because the second term under the radical sign is greater than in the expression which furnishes ρ_1.

Starting from this value of ρ, the term in m is negative, like the term in m^3, and it increases with ρ.

The curve assumes the shape shown in figure 341, and the

ordinates increase more and more in absolute value as they get further from the origin.

(457) We may endeavour to ascertain what becomes of the ratio $\frac{M-Q\rho}{Q\rho}$, which is the measure of the equalization obtained by using flat-rope drums (*reels*). This ratio may be expressed by the equation

$$\frac{M-Q\rho}{Q\rho}=\frac{\left[(Q+2q+pH)\,e+\frac{pH^2e^2}{8\pi\rho^2}-4p\pi\rho^2\right]m-2p\pi e^2m^3}{Q\rho},$$

and we wish to find out its value at the beginning and end of an operation, or when $m=\pm n=\pm\frac{H}{4\pi\rho}$.

It is evident, first of all, as already remarked in No. 455, that with this particular value of m, the two terms $+\frac{pH^2e^2}{8\pi\rho^2}m$ and $-2p\pi e^2m^3$ cancel each other; for by substituting this value for m, we get in both cases

$$\frac{pH^2e^2}{8\pi\rho^2}\,\frac{H}{4\pi\rho}=2p\pi e^2\,\frac{H^3}{64\pi^3\rho^3};$$

From this we get

$$\frac{M-Q\rho}{Q\rho}=\frac{(Q+2q+pH)e-4p\pi\rho^2}{Q\rho}\times\left(\frac{\pm H}{4\pi\rho}\right)$$
$$=\pm\frac{H}{4\pi\rho}\,\frac{(Q+2q+pH)e}{Q\rho}\mp\frac{H}{4\pi\rho}\times\frac{4p\pi\rho^2}{Q\rho}$$
$$=\pm\frac{pH}{Q}\,\frac{(Q+2q+pH)e}{4p\pi\rho^2}\mp\frac{pH}{Q}=\mp\frac{pH}{Q}\left(1-\frac{\rho_0^2}{\rho^2}\right)\ldots(8)$$

This value is equal to zero when $\rho=\rho_0$. This is evident since the value of ρ_0 is precisely determined by the condition that the initial and final values of $M-Q\rho$ should be nothing. Then starting from this value of ρ_0 the factor $1-\frac{\rho_0^2}{\rho^2}$ goes on increasing constantly up to 1, and the function becomes $-\frac{pH}{Q}$ when $\rho=\infty$.

This extreme value is precisely the one suited for cylindrical drums.

This is easily verified by taking the case of a cylindrical drum

with a radius ρ. In the middle of the operation we evidently have the moment $M = Q\rho$; at the beginning it is increased, and at the end diminished, by the quantity $pH\rho$. Therefore at the start $M - Q\rho$ is equal to $+pH\rho$, and at the finish to $-pH\rho$; and therefore we have $\frac{M - Q\rho}{Q\rho} = \pm\frac{pH\rho}{Q\rho} = \pm\frac{pH}{Q}$.

We obtain the same result by making $e = 0$ in the general value of $\frac{M - Q\rho}{Q\rho}$.

In the last equation (8) we may set down *à priori* the final value $\frac{M - Q\rho}{Q\rho} = -a$, and deduce from this the value of the radius ρ by the formula

$$a = \frac{pH}{Q}\left(1 - \frac{\rho_0^2}{\rho^2}\right),$$

which gives

$$\rho^2\left(1 - \frac{aQ}{pH}\right) = \rho_0^2.$$

We get $\rho^2 = \rho_0^2$ when $a = 0$, and $\rho^2 = \infty$ when $aQ = pH$, which agrees with what has just been said.

We can also get, not the final ratio $\frac{M - Q\rho}{Q\rho}$, but the final value of the quantity $M - Q\rho$. Putting this equal to $-A$, we get from the same equation (8):

$$\frac{A}{Q\rho} = \frac{pH}{Q}\left(1 - \frac{\rho_0^2}{\rho^2}\right) \quad . \quad . \quad . \quad \rho^2 - \frac{A}{pH}\rho - \rho_0^2 = 0,$$

from which

$$\rho = \frac{A}{2pH} + \sqrt{\frac{A}{2pH} + \rho_0^2}.$$

We get $\rho = \rho_0$ when $A = 0$, which is always the same verification, and we see how the radius ρ varies in proportion as we make the quantity A vary, or inversely.

(458) If we obtain a value for ρ_1, which is inadmissible *per se*, or an account of the value which would result for the quantity $\rho_1 - ne$, we should adopt a certain radius $\rho > \rho_1$, taking as the basis of our estimate either some of the special points we have been

considering, or the speed of the cage in the shaft, or the number of revolutions per minute of the engine. This radius will have a certain curve corresponding to it like that of figure 341, already alluded to. Though no longer effecting an amount of equalization equal to that of the curve corresponding to ρ_1, still the system always possesses a certain advantage with regard to uniformity over cylindrical drums, and the advantage increases as the radius ρ diminishes. Besides, we can render the load completely regular by using a chain counterbalance, the dimensions of which can be calculated as follows:

Let OC′A′ (fig. 342) be the curve calculated for the radius ρ, which has to be constructed graphically point by point. We then try to find by repeated experiments a straight line OC″A″ which will intersect the curve at a certain point B′, and satisfy the condition that the difference between the extreme ordinates A′A″ shall be equal to the maximum difference which occurs between O and B, and in the opposite direction. This maximum is evidently found at the point C′, where the tangent is parallel to the straight line OC″A″.

The straight line having been drawn in this way, we will now consider the symmetrical line OA″ prolonged towards the negative co-ordinates. Let us make the length $aa''_1 = AA''_1$ represent, on the scale adopted for the figure, the moment of a chain counterpoise, which would have its rope completely wound up at starting, completely unwound at the meeting-place, and completely wound up again on its arrival, in the manner described in detail in No. 453. It is evident that with this chain and the radius ρ we obtain as much equalization as with the radius ρ_1, without any counterpoise.

This is a solution which is perfectly suitable for the case when $\rho_1 - ne$, or even ρ_1 itself seems too small and unfit for the ropes we desire to employ. This solution is suitable for radii ρ as large as we like to make them.

These large radii, which lessen the wear of the rope and enable us to make the cages travel at a high velocity for a given speed of the engine, evidently require heavy chain balances; but to make up for this we approach more closely to the equalization attainable

with round ropes (which is complete with ropes of constant section), because the curve OC′A′ approximates more and more to a straight line.

This is the system which is commonly employed in the mines of the North of England, and when used in conjunction with wire ropes it appears to us to afford the most practical solution yet arrived at of the problem of winding from deep mines with a large output.

It furnishes the means of reaching great depths; it equalizes the power of the engines in a suitable manner, whether they are worked with or without expansion; it enables them to be handled with ease; it allows them to be started without fear at a greater speed, and admits of the cages attaining a high mean velocity, such as 26 to 33 feet (8 to 10 metres) or more per second.

(459) Results analogous to those which have just been examined may be obtained with round ropes by using conical drums. These may either be smooth, with the successive coils laying themselves directly side by side, or they may be provided with a spiral groove. The spiral may be looked upon as generated by the intersection of the cone with a cylindrical surface formed by a generatrix parallel to its axis moved along a spiral of Archimedes traced upon the base of the cone.

Taking the case generally, let ϕ denote half the angle of the apex of the cone, and l the constant distance apart between the axes of two successive coils measured along a generatrix, the whole of the theory set forth in the preceding paragraphs will hold good by substituting for e its value $l \sin \phi$ (fig. 343).

If, on the other hand, the coils touch one another, the distance l is simply the diameter of the rope; and if we denote this diameter by d, $e = d \sin \phi$ (fig. 343).

By substituting for e the value $d \sin \phi$ in the equations just given, we can obtain the data similar to those for flat ropes; and we have the power of making them vary with any given rope, because we can alter the two elements l and $\sin \phi$. Consequently, within certain practical limits, we can effect alterations in the quantity e which enters into these equations.

It has been proposed to arrange the conical drums so that they shall receive only the first coils of the rope, the remainder being wound on a cylindrical part at the end of the cone; in other words, instead of joining the two cones directly by their larger bases, they are separated by a cylindrical portion (fig. 344). Thus on starting and stopping we obtain the equalization effected by conical drums, and in the middle of the operation there is necessarily the variation attendant on cylindrical drums. This would be represented by substituting for the curve expressing the moments a straight line of a certain length, such as DD′ (fig. 345) near the point of inflexion at the origin of the co-ordinates. This is evidently permissible.

The use of the spiral drum may be extended and completed by suppressing the cylindrical part and making it take the whole of the rope.

Besides, by varying the quantity $e = l \sin \phi$ from one turn to another, we can effect any amount of equalization we wish. This may be accomplished by altering $\sin \phi$; that is to say, by replacing the conical surface of the drum by a surface generated by the revolution of a suitably constructed curve round the same axis, and taking the intersections of the spirals on it at constant distances apart. Again the angle ϕ might be left unaltered, *i.e.* the conical surface retained, and we might vary the distance l along the generatrix of any two consecutive spires.

(460) All that now remains to conclude the subject of ropes is to point out how they are joined to one another, or to the ends of the chains by which they are fastened to kibbles or cages.

It often happens that *splices* have to be made; that is to say, several pieces of rope have to be joined end to end either for the purpose of lengthening a rope or restoring it to its original length after parts accidentally injured have been cut out.

Round ropes are prepared for making a splice by untwisting them for a length of 2 ft. or 2 ft. 4 in. (60 to 70 centimetres), and then untwisting separate strands themselves. Each yarn is then thinned to half its thickness, or else each alternate one is cut out; then the remaining yarns of two strands, one from each rope, are

laid together. A complete strand is made up in this way, and with the different strands a complete rope. The splice is then whipped round with cord, and the whipping continued beyond both ends of the splice, and the cord fastened by a knot.

A splice of this kind, if well made, will *resist a tensile strain* quite as well as the rope itself; it is merely somewhat bigger and less flexible. It nevertheless causes a *weak point* in the rope on account of the bend produced in the rope on both sides of the splice where the bulging piece passes over the pulley or drum.

With flat ropes the simplest plan seems to be to rivet to their ends flats shackles connected by a ring or hinge. Flat ropes may also be spliced like round ones by splicing each separate component rope, and re-sewing the whole for a length of 6 to 10 feet (2 to 3 metres).

In order to provide a means of fixing a chain to the lower extremity of a round rope an eye may be fastened on. The eye is like a small pulley, and the rope is coiled round it. For the purpose of making the rope bend more easily it may be unlaid for a short distance. The unlaid part is then bent round the eye, and the ends brought back along the rope, and the whole well whipped round with cord for some distance, in the same way as when splices have been made.

With a flat rope we can rivet on a shackle with an eye, which receives the first link of the chain. Another plan is to untwist each separate rope and bend back the strands right and left round a bolt passing through a shackle riveted to the rope. Sometimes also the rope is bent back on itself, but there is a greater risk of straining it in this way.

These various arrangements, and the plans for preventing chains from becoming unhooked, are shown in figure 346, and need no further explanation.

(461) On leaving the drums, or the reels, the ropes pass over pulleys fixed on the top of pulley-frames, and then hang down into the shaft.

The pulleys, or sheaves, have a flat or round groove, according to the kind of rope used, and they should be *large* and *firmly fixed.*

The object of the first condition is to preserve the rope by avoiding any sharp bends. The second condition is rendered necessary by the great load which these pulleys have to sustain. Let us take, for instance, the case of the full cage just after it has started; the load on the axle of the pulley is the resultant of two forces in the directions of the two parts of the rope, each equal to the quantity $Q+q+p$ H. Taking the numerical values given above, this is equal to $1600+2000+7\times400=6400$ kil. ($6\frac{1}{4}$ statute tons).

The resultant would therefore be 12,800 kil. ($12\frac{1}{2}$ tons) if the part of the rope going to the drum were nearly vertical, and it would be $6400\sqrt{2}=9014$ kil. (8 tons 18 cwt.) in the extreme case of its being horizontal. In the first case the resultant would be vertical, and in the second it would be at an angle of 45°.

As a rule, therefore, in order to form an estimate of the statical conditions of the system, we must take the effective tensile strain on each rope, and see what is the resultant pressure, along the bisectrix of the angle between the two parts of the rope, on the axle of the corresponding pulley.

The size of the axle of the pulley must be calculated accordingly, and we must look upon the pulley-frame as being acted on by two distinct forces, of which the directions and points of application are known, and of which we can ascertain the amounts at each instant.

The groove in the pulley should be sufficiently wide and deep to afford the rope a certain amount of play. This play is *useful* with flat ropes to allow for any want of precision in fixing the pulley, which would prevent the vertical plane passing through the middle of the pulley from coinciding exactly with that of the cage. It is *indispensable* in the case of round ropes, because as these are wound round a drum they do not always remain in the same plane. The rim containing the groove is usually made of cast iron. Sometimes, however, and especially in the case of wire ropes, the groove is lined with wood on end, or has one turn of an old hemp rope put round it, so as to reduce the chafing which might be caused by friction if the rope happened to slip in consequence of rapid variations of speed or tension. Sometimes the

pulley is made entirely of cast iron; but a good plan for very large pulleys is to make the box and rim of cast iron and the arms or spokes of wrought iron, which are cast in.

Pulleys are often 8, 10, or even 12 feet* in diameter ($2^{m}\cdot50$, $3^{m}\cdot$, or $3^{m}\cdot50$), and they may weigh 29 to 35 cwt. (1500 to 1800 kil.), and even exceed 2 tons. The three figures numbered 347 represent various kinds of pulleys described in the Appendix.

The pulley-frame, called also poppet-heads, shaft-tackle, head-gear, head-stocks, pit-head frame, is a kind of shears carrying the pulley. It ought to stand on a timber framework, the base of which should be so large that the resultant of the forces described above should always fall within it, and indeed not near the outer part of it. Where this cannot be managed the pulley-frame must be stayed with spurs, which may be footed, for instance, against the house of the winding engine.

There are two other necessary attributes of a pulley-frame. The first, and most indispensable, is that it should be made sufficiently strong to be fully able to resist not only the ordinary heavy strains, but also any exceptional strains to which it may be subjected in case of an accident, where it might be necessary to use all the power which the engine could exert, and all the shocks or vibrations which may be produced during these operations or in the regular course of working.

The second condition is that it should be high enough to prevent *overwinding; i.e.* the cage being drawn up against the pulley through a very slight inattention of the engine-man. The necessary height depends upon the speed of winding, but it should generally be *at least* 33 feet (10 metres). Even with this height inattention on the part of the engine-man for *one or two seconds* (half a revolution for a 25 feet drum) would suffice to cause an accident, if he did not take care to slacken speed as the cage approached the surface, so as to have it thoroughly under command the moment it made its appearance.

Pulley-frames are most frequently constructed of timber; but in countries where it is not usual to build a house of masonry over the top of the shaft, the pulley-frame decays rapidly, from

* Pulleys 16 or 17 feet in diameter are not uncommon.—*Translators.*

being exposed to the weather and constant strains, and has to be renewed wholly or in part at the end of a few years. In order to prevent the cost of repairs the head-gear is sometimes constructed of iron; the legs are made of double T section or circular, so as to ensure strength, while at the same time material is economized. (*Cours de Machines*, vol. ii.) This arrangement may be recommended, and seems likely to come into use more extensively. Another good plan consists in substituting for the wooden or iron pit-head frames a round or square tower of masonry, which forms as it were a continuation of the shaft. Openings are left in the tower for all necessary requirements of the mining operations, and, besides this, it is made to receive the ends of the buntons, or dividings, by which the shaft lining is prolonged, and the wooden or iron beams on which the bearings of the pulleys rest.

Perhaps this system leaves the top of the shaft somewhat less free, unless the tower is built with a very large base; but it has the advantage that it can easily be constructed in a most firm and durable manner without requiring timber of large dimensions, which is not always readily procurable in every country. It is also especially suitable for hot climates. Figures 348 to 351 give examples of the three systems just described. They exhibit some special arrangements which will be easily understood from mere inspection, and for the details of which we must refer the reader to the explanation of the plates.

§ 3. Various arrangements employed in winding.

(462) The two preceding paragraphs have been devoted to a description of the different motors employed for winding, and of the intermediate organs between the receiver of the power and the extremity of the rope which acts upon the operator, properly so-called, *i.e.* the vessel containing the mineral which has to be raised to the surface.

All this may be explained in a general way without introducing the question of *winding* or *hoisting, properly so-called;* viz., the choice of the apparatus to be used, and of the operations to be performed, in order to receive the mineral at the onsetting place

(*plat*), raise it to the surface, and deliver it at the top of the shaft, or tip it over the rubbish-heap (*burrow*).

The most varied arrangements have been adopted for this purpose, but it would be impossible for us to describe them all in detail, or even to enumerate them. Some indeed are obsolete. Nowadays there is a tendency towards a single type, varying occasionally in its details, though not in principle. The use of this type is ratified by experience, and it becomes more and more indispensable as the shafts increase in depth, diminish in number, and are required to furnish larger outputs.

We shall cite a few examples, and we shall lay particular stress upon this principal type to which we have just alluded.

We must refer the reader to the *Cours de Machines* (plates I., II., and IV.) for the various arrangements that may be adopted for sinking shafts, in which the kibbles are drawn up by men or horses; and we will now suppose that we have to deal only with the case of winding from a permanent onsetting place (*plat* or *lodge*).

Paragraph 389 contains a description of the various types of rolling stock used for conveying mineral underground; and, according to the manner in which the mineral is raised to the surface, they were there divided into three classes:

1. Waggons emptied at the hooking-on place (*plat*), the mineral being filled into corves or kibbles which work in the shaft.

2. Trolleys which carry kibbles along the main roadways to the hooking-on place. The kibbles alone are raised to the surface, whilst the trolleys remain below ground. The empty kibbles are taken back on the trolleys to the working places, and are then refilled, and so on.

3. Lastly, tram-waggons or tubs which are loaded at the working place, brought out to the shaft singly or in trains, and then raised to the surface without being unloaded in the interim.

Forty years ago winding was carried on almost exclusively with kibbles or corves in France and Belgium.

At *Mons* the coal was drawn up in large wooden kibbles bound with iron, containing about 70·6 cubic feet, or 55 bushels (20 hectolitres). These were placed in a cavity at the hooking-on

place, called the *Pas de Cuffat.* (See plate xxiv., fig. 189.) This cavity was made large enough to hold two or three kibbles, so as to prevent any loss of time in sending them off. As soon as one kibble could be filled another empty one was brought down to replace it, and the chains were simply unhooked from the empty kibble and hooked on to the full one. The speed of winding was slackened just before arriving at, and just after starting from, the hooking-on place, and the kibble was drawn in, or steadied on its way out, by means of an iron hook at the end of a long pole.

On arriving a little above the surface the kibble was drawn to the edge of the pit, either by hand or by means of a piece of chain made fast at one end and having a hook at the other which was passed into a ring at the bottom of the kibble. The engine was then reversed, and the kibble descended a little; but being at the same time drawn in by the chain, it was lowered over on its side at a particular spot. The chains were then unhooked and attached to the empty kibble, which was then in its turn brought into position ready to be lowered on receiving the signal from below. One end of a piece of chain passing over a pulley was then hooked into the ring at the bottom of the kibble, and the other end was wound up by a windlass; in this manner the kibble was lifted up and completely emptied of its contents. The windlass was worked by hand, or it was driven by the engine by means of some arrangement that could easily be thrown in or out of gear. The kibble having been thus emptied, was then lowered again on to the ground, the speed being regulated by a break, if necessary, and it was set aside in a suitable place, leaving room for the full kibble, supposed by this time to be approaching the surface, and was ready to replace it and be sent down again.

Figure 352 represents one of these large kibbles in the position into which it was brought for being emptied; and figure 353 shows the arrangement for tipping it by means of the engine during the next operation of winding.

At *Rive-de-Gier* kibbles were used having a capacity of 28 to 35 cubic feet (8 to 10 hectolitres), being thus much smaller than the large *Cuffats* of the Mons district. They were generally set up on

a platform in the shaft itself just below the *plat*, for the winding was usually carried on from one level only.

On arriving at the surface the full kibble had to be emptied at some distance from the shaft. For this purpose it was drawn by a chain, in the manner described above, on to a little trolley, and trammed to the tip; while, at the same time, another trolley with the empty kibble of the previous operation was brought back to the shaft. In order to enable the men to tip over the kibble and right it again easily, it was supported on two bearers each cut in the form of the arc of a circle, having its centre a little above the centre of gravity. By rocking the kibble gradually it was easily tipped over, and then brought back again into its original position.

At *Saint-Etienne* the kibbles were small and elliptical in shape, and were conveyed along the roadways on trolleys. They were attached to the main chain, two at a time, by means of four short pieces of chain fastened to one of the links; and as the short chains were hooked on at the extremities of the major axis, the kibbles were forced to hang close together. There were sometimes two or three large links at short distances apart in the main chain, to which the four little chains were fixed on, and, consequently, two or three groups of two kibbles could be raised together. On leaving the hooking-on place the chain was drawn up slowly, and the kibbles were steadied by hand, and in a similar manner they were landed at the surface, but in the opposite order, while the engine was being reversed.

In the three foregoing examples the vessels for raising the mineral were not guided in the shaft. It was, therefore, necessary to wind them up and down slowly so as to prevent their striking against the sides of the shaft, and *very slowly* indeed where they passed each other, the shaft being also purposely made larger at this point in order to give more room for passing.

Under these conditions the average speed of winding did not usually exceed about 3 feet (1 metre) per second, and it was sometimes as low as 2 feet ($0^{m}{\cdot}60$).

(463) A great step in advance was attained by making arrangements for guiding the vessel containing the mineral during its

journey through the shaft. This system preserves the kibbles and sides of the shaft from wear, prevents any danger at the meeting-places, and enables the speed of winding to be increased very considerably.

Various methods of guiding have been adopted, but they may all be referred to three principal systems.

The first consists in simply dividing the pit into compartments, carefully lined, and just big enough to let the corve or kibble pass with little play. In this manner there is no danger at the meetings, and the speed of winding can be increased without any fear of the kibble striking violently against the sides, which it probably would do if it were possible for it to swing horizontally to any extent while proceeding at great speed.

This system is very much the same as that which is pursued in working many mineral veins where the shafts are sunk along the dip of the deposit. The kibble slides on two lines of bed-plank or poles, carefully fixed to sleepers on the foot-wall, and it is kept from moving sideways by a projecting border. To prevent the kibbles from being worn, they are sometimes furnished with runners like those of figure 262, only placed on the sides instead of on the bottom. Sometimes rollers or wheels are used instead of runners, resting on longitudinal guides, and then the vessel (*skip*) becomes a sort of waggon moving on a very inclined road. On arriving at the surface the kibble is emptied by being tipped completely over by means of a hook and chain in the manner described above, as the system adopted at Mons; it is not, however, unhooked from the rope.

These systems are represented in figures 354, A, B, and C, and they are further described in the Explanation of the Plates.

Another plan is to have a sliding cover for each compartment of the shaft, which runs over it on lifting up a balanced gate, which closes the front part of the landing. The landers or banksmen are protected by the gate from falling into the shaft while the rope is working in the open compartment, and by the sliding cover while the skip or kibble is being landed. This arrangement, which is shown by figure 355, may be considered fairly satisfactory.

The second system is that of employing wire-ropes for guides.

The ropes are tightly stretched between beams carried on the head-gear and others fixed at the bottom of the shaft. Sometimes the ropes are brought over pulleys, and then fixed at the base of the pit-head frame.* Four wire-ropes are put in, in two pairs, each pair serving for one kibble. The extremity of the winding-rope is attached by two short pieces of chain to a horizontal bar with an eye at each end, which can be opened and made to clasp the guide rope. Two chains are fixed to the under part of the bar, and the kibble or waggon is hooked on to them.

A narrow drawbridge is let down between the two guides when the kibble has come up above the surface, and it is landed by reversing the engine. A similar arrangement is employed at the hooking-on place.

For the purpose of hoisting several kibbles at a time a stirrup-shaped iron frame is fastened to the rope instead of the cross-bar. It is made with eyes above and below, through which the guides pass, and it is long enough to receive several kibbles one above the other. The kibbles are provided with hooks on their sides, which are caught by projecting pins in the frame.

The landing is easily effected. When the stirrup has been drawn up above the level of the landing-place, the gate is let down, and the engine is reversed slowly. As soon as the bottom kibble rests on the gate it is set free, and it is then at once drawn away to make room for the next. All the full kibbles are taken off in this way, and empty ones are put in their places, and hooked on successively by raising the stirrup slowly. The cover is then drawn away; all is now ready at the surface for the next operation, and the engine is started again as soon as the signal is received from below.

This system, which is represented in figure 348, already referred to in No. 461, is only suitable for shallow mines, not deeper than about 250 yards; and the greater the depth of the pit the slower must be the speed of winding. Beyond that depth, and especially with quick winding, there would be a danger of the guide ropes oscillating considerably, and perhaps causing accidents at the meetings, if the guides were too close.

* The plan usually adopted in this country is to hang very heavy weights at their lower ends, while their upper ends are made fast to the pulley-frame.—*Translators.*

There is also the disadvantage in this system, although some attempts have been made to remedy it, that safety catches cannot be applied with it. These form an interesting, though not necessary, feature in the third system, which we must now proceed to describe.

(464) This last system is that of *cages with guides.* Instead of the guide being flexible, and to a certain extent loose, as is necessarily the case with a rope, it is fixed, and made up of a series of pieces of timber, joined together vertically end to end, and fastened to beams (*buntons, dividings*) placed across the shaft at regular intervals. In exceptional cases, such as in an upcast shaft near a ventilating furnace, iron guides may be employed. They last longer, but are more expensive to put in, and are not well adapted for most kinds of safety catches.

There are two lines of guides for each cage. The cages are rectangular in section, and to prevent oscillation as much as possible the guides are generally put in on the small sides of the rectangle. As a rule, the cages are two-decked, each deck receiving one or two tubs. The actual guiding is effected by means of iron *shoes,* which are fixed near the top and bottom of the cage, and grasp the wooden conductors pretty closely.

As the cage adds considerably to the dead weight which has to be raised, it should be made as light as is compatible with the requisite strength. Steel is well adapted for making cages, as it combines strength with comparative lightness. As wooden conductors are generally fixed on the shorter sides by which the tubs usually enter, they must be left out at the onsetting places where the tubs have to be run in and out. If they were simply left out for a space less than the total height of the cage no special arrangement would be necessary, as the cage would still always be guided. But, as a rule, it is necessary to fix *false conductors* in these places, which are grasped by another set of iron shoes. The cage is thus always between conductors, either at the two ends during the greater part of its transit through the shaft, or at the two sides at the level of the onsetting places.

It rarely happens that the section of the pit is sufficiently large to

allow of the cages receiving their full load on one and the same floor. It may be remarked, however, that we have more margin for enlarging the horizontal dimensions of the cage than would appear possible at first sight, because at the time when one cage is at or near the top the other is at or near the bottom; and there is no reason why they should not then be vertically one above the other, provided they are kept properly apart at the meeting-place. The two sets of guides may therefore be fixed as close to each other as may be thought desirable at the surface and at the bottom so long as they are gradually separated on approaching the meeting-place, where the shaft may have to be enlarged. This plan may be very useful in the case of an old pit, sunk too small originally, where it is wished to put in conductors for cages, and also in the more general case of there being some reason for reducing the space occupied in the shaft for winding purposes.

There is no disadvantage in this method; and we may remark that it can be applied in the case of kibbles, which are not guided, as well as with cages. In one instance, however, it cannot be employed, and that is with wire-rope conductors, because these must be stretched *in a straight line* for their entire length. With the exception of this case, it may be said that *theoretically* the section of the pit need only be large enough for the passage of one cage or kibble, save in the neighbourhood of the meeting-place. In spite of this possibility, which we notice incidentally, it very often happens that we are induced to construct the cages with several floors. These floors or decks are generally two or four, and rarely an uneven number. Each deck will receive one or two tubs, generally placed end to end, and rarely side by side. If the cage has only two decks, the winding cannot be carried on with proper rapidity, unless there are means of landing and onsetting at both decks at once. These must therefore be kept sufficiently far apart, or, in other words, the cage must be high enough to allow plenty of space for men to work between the two floors, which correspond to the two decks of the cage when stopping at the surface. Where the cage is four-decked the tubs are run off and on at the first and third decks, and then at the second and fourth, and it is consequently necessary to make an extra operation

with the engine; for the cage must be stopped on the keeps at the first deck, and then again at the level of the second. Two consecutive decks may then be twice as close as in the first instance.

During the interval between the successive arrivals of two cages, the banksmen of the upper landing let down the full tubs on to the lower floor, which is the real level for landing, and raise up the empties which they require to replace the full ones of the next turn. For this purpose they employ a double-acting lift, in which the full tub raises the empty one; or else a single-acting lift, in which the full tub raises a counterpoise, which in its turn lifts up the empty tub. There is no difficulty in carrying this out in the interval between the arrivals of two successive cages, and consequently the winding is in nowise hindered thereby. Besides, if necessary, special workmen can be employed for conducting this operation. Sometimes also these lifts are worked by transmitting power from one of the winding pulleys; and the ascent and descent are effected during one journey of the cage in the pit. This system does not seem particularly useful.

Analogous arrangements may be made at the onsetting places; only here the upper deck is the level at which the full tubs arrive, and they have to be let down to the lower deck, whilst the empties have to be lifted up. This raising and lowering may be effected by single-acting or double-acting lifts, like those at the surface, constructed at the side of the onsetting place.

As these lifts require a good deal of space underground, they may be sometimes replaced with advantage by inclined side galleries, or single or double-acting inclined planes, which overcome the difference of level between the two decks.

Side galleries are also sometimes driven on a level round the shaft so as to enable the empty tubs to be run off on one side and the full ones run on at the other. The two operations of running the tubs off and on are carried on simultaneously, the full tubs pushing off the empty ones. In this manner there is no crowding together of full and empty tubs, and the onsetting is performed with all the speed desirable. Furthermore, this plan enables the onsetting place to be made narrower, which may be an important advantage in some kinds of ground.

At other times, when the cage is four-decked, the onsetting place for the first and third decks is made on one side of the shaft, and the one for the second and fourth decks on the other; and then the empty tubs can be withdrawn and the full ones pushed on *without moving the cage.* Side galleries or inclined planes are made to connect the various onsetting places, so as to make it possible to distribute the tubs between them equally; for, as a rule, they arrive at the opposite sides of the shaft somewhat irregularly.

Whatever may be the system adopted, and numerous variations are possible, it is important that all the operations should be carried on *with the greatest rapidity;* and it is with a view to rapidity that all arrangements should be devised in planning winding apparatus.

First of all it is necessary to have a winding engine adapted for all the operations, and well under the control of the engine-man; then there must be means of readily loading and unloading the cages, both at the surface and underground; and as far as possible the work at the two places should be carried on *simultaneously,* without its being requisite to handle the engine first for *landing* and then for *onsetting.*

The simplest plan is to arrange matters so that the cage need not be moved at all during the onsetting. The descending cage is received on the keeps, and remains there until all the decks have been unloaded and reloaded, which is very easily accomplished, as we have seen above, even with four decks.

As soon as the onsetters are ready for the cage to start they give a signal to the engine-man, and they need not trouble themselves any more about it.

Whilst one cage is stopping at the onsetting place, the other, which has reached the surface, is twice lowered on to the same keeps for the purpose of unloading the different decks. It is then lifted, so that the keeps may be opened, and lowered gently into the shaft just enough to bring the other rope into a state of tension. The engine-man now waits for the signal from below, or if he has already received it, he at once lowers the cage.

Owing to the elasticity of the ropes, and there being a short

piece of chain between the end of the rope and the cage, there is no difficulty in leaving one cage on the keeps at the bottom whilst the other is being handled at the surface, without running any risk of doubling up the ropes in the shaft, and so injuring them.

This arrangement renders the work of the onsetters independent of that of the banksmen, and the loss of time is reduced to a minimum.

The keeps consist of an assemblage of levers and rods, which work either oscillating catches backwards and forwards, or else horizontal bolts on which the cages can rest.

Sometimes the keeps are arranged so as to be *self-closing.* The cage opens them on reaching the pit top, and they then shut of themselves, so as to be ready when the cage comes down to rest upon them. The banksman has merely to open them for an instant when the empty cage has to be lowered into the pit.

Sometimes, on the contrary, the keeps are *self-opening,* and the banksman has to shut them in order to receive the cage. They then remain closed of themselves, owing to the weight of the cage which overcomes the weight of the counterpoises that serve to keep them open. This latter plan appears the better of the two.

Various means are adopted for closing the compartments of the cages, and there is no difficulty in inventing new methods. One of the simplest and commonest arrangements consists in having a latch hanging vertically in front of the top of the tub. It is lifted up by hand and turned back, and remains in this position while the tubs are run in, and is then at once shut down again.

Figures 356 to 364, which are readily understood, and which are further described in the Explanation of the Plates, represent some of the arrangements and machinery referred to in this paragraph.

(465) It appears to us that by adopting arrangements and machinery of this kind, the *innumerable varieties* of which need not be described in detail, we bring the process of winding to as great a perfection as the present state of the art of mining will admit.

This system satisfies all the conditions we can wish for. Thus, in the first place, the coal or ore loaded at the working places

arrives at the surface without any transhipment, which economizes labour and reduces the quantity of smalls. Then again, by marking the tubs it is easy to tell at once at the surface whence the mineral is derived, and this enables the agents to keep a useful check on the work that the miners are doing. Lastly, if the engine is strong enough, and the hauling and winding well arranged both underground and at the surface, the tubs can be raised at great speed with an interval of a few seconds only between the successive turns, so that as a rule there will be no difficulty in raising to the surface all the mineral that can possibly be produced.

In case the ordinary winding machinery is not able to cope with the possible output (and this does happen in some collieries of the North of England, where workings are carried on in seams lying in the most favourable conditions, and are extended to exceptional distances from the shafts), it would be quite possible to sink pits of very large diameter, sufficiently large in fact to allow of *two sets of winding-gear*, with distinct compartments and onsetting places.

This, indeed, is the system that has been adopted in a small number of mines in the neighbourhood of Newcastle and Sunderland, and the daily output of certain pits has been brought to nearly 2,000 tons. In reality, however, a pit of this kind may be looked upon as two ordinary pits, the axes of which coincide. Of course this plan lessens the *first cost* of sinking, and simplifies the work to be done above ground. But there must be exceptionally favourable conditions *underground* if it does not increase the *cost of working*, on account of increased expense for hauling, keeping up tramways, ventilation, &c. There are few localities in France where it would be advisable to employ this system in preference to having two distinct pits to divide a large working area between them.

In England itself we can cite examples of a *directly opposite* system, especially in the metallic mines of Cornwall. There it is not an uncommon thing for *one single* central engine to be employed to wind successively from *several pits* more or less distant, each one of which has so small an output that it requires the services of the engine only for a day or two, or for a few hours a week.

CHAPTER XVII.

NUMERICAL DATA AND VARIOUS DETAILS RELATING TO WINDING.

(466) In the preceding chapter we described the machinery which is essentially necessary for the service of winding in any given mine, together with the method of handling it. The explanation was sufficiently exhaustive to enable the subject to be understood clearly.

In the present chapter we shall give some numerical results with which the engineers should be acquainted, and we have reserved them to the last so as not to interrupt the technical descriptions and remarks. We shall afterwards enumerate various arrangements which have been proposed, but are not yet widely adopted in practice; and although they cannot be considered to be *indispensable*, as it were, to the principal object we have before us (namely, the operation of winding), they may nevertheless be regarded as more or less interesting improvements.

Hence the two sections into which the present chapter is divided.

§ 1. Numerical data relating to winding.

(467) To sum up what was said in the preceding chapter, it appears to us that the service of winding applicable to the most important case we can consider, from a technical point of view (namely, that of *a deep mine having a large output*), will be as well organized as it can possibly be if it satisfies the following conditions:

1. *The winding engine* should be constructed on the type defined in No. 436, and further described in No. 442; that is to say, it should have two cylinders, horizontal or vertical, driving the same shaft directly without gearing; it should work at a high pressure with variable expansion; and it should be connected with a special engine, erected close by, for the express purpose of feeding the boilers and condensing the steam of all the engines employed about the top of the pit.

It should be provided with easily-worked reversing gear, which satisfies the double condition of employing expansion during the ascent of the cages, and suppressing it while they are being started and landed.

The dimensions of the cylinders should be taken sufficiently large, that one piston alone, acted on by the normal pressure of steam in the boilers, and without the assistance of the condenser, will, when placed in the middle of its stroke, the other piston being at its dead point, be able to overcome the maximum of resisting work and *raise the cage.* For example, supposing one of the ropes to be broken while a loaded cage is suspended at the extremity of the other, then the engine must be strong enough to start with this unbalanced load from any position whatever. This condition determines the diameter of the piston; for we must make the virtual work of the effective pressure upon it equal to the virtual work of the principal resistances, augmented by from $\frac{1}{3}$ to $\frac{1}{4}$, to make due allowance for the passive resistances of the engine itself.

A piston whose size is calculated in this way will be *much too large* for the ordinary work, which is carried on by the combined action of the two pistons. This would be a serious disadvantage if neither expansion nor condensation were resorted to (see No. 437); but it will be compensated in a natural way by proportioning the cut-off to this excess of power, and owing to the presence of the condenser the expansion itself will not have the disadvantages due to a counter-pressure equal to, or slightly greater than, that of the atmosphere.

2. *As regards the ropes and their appendages,* it may be said at once that wire ropes ought *unhesitatingly* to be preferred to those

composed of vegetable fibres; and, if the pit is *very deep*, flat ropes ought to be preferred to round ones, and steel wire to iron wire. Moreover, the ropes will also be *tapered* when the depth is very great.

They will be sufficiently safe if they are constructed of wire of suitable quality, and if the total load at any given point is not more than a thousand times the weight of the rope per metre in the case of iron wire, and fifteen hundred times in the case of steel (550 or 820 times the weight per fathom).

The dimensions of the drums ought to be calculated in accordance with the theory set forth in Nos. 454 *et seq.*, which determines approximately the mean radius of the coil. If the mean radius, or the minimum calculated radius, be too small, there should be no hesitation in substituting a larger radius, with a view to the better preservation of the ropes; and further, after the special examination which should be made into this question, it may be found convenient to complete the equilibrium of the machinery by the addition of a chain counter-balance, or by some other equivalent arrangement.

The minimum radius of drum that can be taken for a rope of any consequence is 3¼ feet (1 metre) at least, if we desire to avoid straining it too much whilst it is being coiled.

The same consideration fixes, within narrow limits, the smallest diameter that can be given to the pulleys. The pulley frame ought to be 30 feet high at least, or, better still, 40 feet, 50 feet (10, 12, or 15 metres), or more, above the level at which the tubs are landed.

3. Lastly, *as regards the actual vessels in which the mineral is brought to the surface*, the system to be generally preferred, under the circumstances we are now considering, is that of cages with wooden guides.*

Amongst the numerous variations of which this system is susceptible, we think that, if rapidity of winding is the principal object to be considered, and if the size of the shafts permits of it, the plan of having two-decked cages, each carrying two tubs placed end to end, is the best that can be adopted.

* Of recent years wire rope guides have been largely introduced into this country for use in vertical shafts with excellent results.—*Translators.*

At the surface the cages will be received on catches (*fangs, shuts, keeps*), placed in such a position that the lower deck will be on a level with the floor of the landing-place, while the upper deck stands opposite to a platform placed about 6 feet higher.

The two decks are unloaded simultaneously without using the engine; and, in the interval between two winding operations, the full tubs are let down from the higher platform, and empty ones are drawn up to replace them.

At the bottom the two decks are likewise loaded and unloaded simultaneously, and without any movement of the engine, by means of two corresponding onsetting places. These communicate with each other by a sloping road, which permits of the tubs being equally distributed between them, whatever may be the individual outputs of the cross measure drifts which lead to them.

With this system not more than 12 to 15 seconds are consumed between two runs of the engine, and four tubs may be raised at a time; or, according to the figures given in No. 408, at least 27 cwt. (1,400 kilogrammes), and even as much as 2 tons of useful weight.

In a pit 400 yards (400 metres) deep, with carefully arranged fittings, the cages may run at a speed of 25, 30, and even 40 feet (8, 10, and even 12 metres) per second, and thus wind at the rate of 2 tons per minute, or at the rate of *more than* 100 tons an hour, allowing several minutes every hour for loss of time from unforeseen circumstances.

Assuming a velocity of only 25 feet (8 metres in the French example), the theoretical power of the engine when winding is

$$\frac{25 \times 60 \times 2 \times 2240}{33000} = 204 \text{ horse-power}$$

$$\left(\frac{2000 \times 8}{75} = 216 \textit{ chevaux-vapeur}\right).$$

Some persons prefer to increase the load and diminish the speed. It is evident that with a useful weight of 4 tons, and a velocity of $12\frac{1}{2}$ feet, the same horse-power will be developed as in the previous case. It might be thought also that, as the total number of runs per hour would be thus reduced, the loss of time due to handling the tubs would be reduced in the same proportion, and that the

output per hour would rather be increased than diminished by the change.

The last advantage, which is somewhat hypothetical, and in any case very slight, would be found more than counterbalanced by the double inconvenience of having to increase beyond measure the dead weight corresponding to the useful weight, and consequently the strength of the ropes, the pressure on the pulleys, &c., and afterwards in having to establish a greater degree of punctuality between the three services of haulage underground, winding, and haulage at the surface, from which loss of time would result at one time, and obstructions at another.

There can be no doubt that the system of *medium* loads and *high* velocities, within the limits given above, merits the preference.

(468) When we come to consider the cost of winding calculated on the ton of mineral raised, it may naturally be expected that this varies between the widest limits, and a special study of the question ought to be made in each particular case. Whatever may be the system employed, it is generally observed that the cost per ton *diminishes* for a given output as the depth *increases*, and that the same thing occurs if the output increases while the depth remains the same; for, amongst the items which go to make up the total cost in this case, there are some which increase proportionally, or perhaps rather more than proportionally, with the depth on the one hand, and with the output on the other; others, on the contrary, increase in a much smaller ratio than the depth or the output; and lastly, there are others which are almost independent of both.

We could not therefore *à priori* quote even an approximate cost either *per ton*, or *per ton raised* 100 *yards*, and the result which we are going to bring forward holds good only for the case to which it refers.

We shall suppose a shaft of 400 yards (400 metres) with an output of 600 tons (600 metric tons) per day.

Then the daily expense can be approximately estimated in the following way:

1. *Wages*—

	s.	d.	francs.	
1 Engine-man . . .	4	0	(5)	
2 Stokers . . .	5	7	(7)	
2 Hitchers or onsetters .	8	0	(10)	
2 Assistants . . .	4	10	(6)	
4 Banksmen . . .	12	10	(16)	per ton (per metric ton)
Total . . .	35	3	(44)	say 0·70d. (0·073 fr.)

2. *Coal*—

The daily work amounts to 600 × 2,240 × 400 × 3 = 1,612,800,000 foot-pounds ($600{,}000^k \times 400^m$ = 240,000,000 kilogrammetres); or, let the work be taken at that of 800 horse-power (800 ch.) developed during one hour. We may suppose that, even with the employment of expansion and condensation, the consumption of coal will amount to 11 lbs. (5^k) per horse-power per hour (*much more* than this is consumed by most winding engines), in consequence of the intermittent nature of the work, the irregularity of the resistance, and the frequently inferior quality of the coal supplied, at collieries at any rate. Say 4 tons per day at 8s. (10 fr.) = £1 12s. (40 fr.); or, per ton raised . . . . 0·64d. (0·067 fr.)

3. *Ropes*—

We shall suppose 1,000 yards of rope to be in use at a time, including the spare parts which remain on the drums, and the parts which extend from the drums to the cages, passing over the pulleys. Adopting an average weight per yard of about 14 lbs. (7 kilogrammes per metre), at a price of 5¼d. per pound (1 fr. 20 c. per kilogramme), and supposing a rope to be renewed at the end of one year's service, or after it has raised 600 × 300 = 180,000 tons, the annual cost will be $\frac{1{,}000 \times 14 \times 5\frac{1}{4}\text{d.}}{12 \times 20} = £306$ (1,000 × 7 × 1·20 = 8,400 fr.); or, per ton raised . . 0·41d. (0·047 fr.)

4. *Repairs of the engine*—

The current repairs of the engine, supposed to be one of 150 horse-power (150 ch.), may be taken at £1 4s. (30 fr.) per horse-power per annum, or £180 (4,500 fr.); or, per ton raised . .	0·24d. (0·025 fr.)
Total	1·99d. (0·212 fr.)

In round numbers we may take the cost at 2½d. (0·25 fr.) per ton, including the small expenses due to maintaining the accessory plant in repair, and any unforeseen accidents that may occur.

We shall say therefore that the cost is 2½d. (0·25 fr.) per ton raised, and this gives us *per ton per mile*, $\frac{2\frac{1}{2}\text{d.} \times 1{,}760}{400} = 11\text{d.}$ (*per metric ton per kilometre*, $\frac{0{\cdot}25 \text{ fr.}}{0{\cdot}4} = 0{\cdot}625$ fr.).

It may be remarked here in passing, that raising a metric ton to the height of a *kilometre* (7,233,140 foot-pounds) is just the amount we have adopted for the daily work of a horse. The cost (0·625 fr.) should therefore be compared with that of a horse for one day; and further, in this comparison we are neglecting altogether the accessory expenses, such as wages and cost of keeping in repair, which we should have with a horse-gin. The question of economy leads us therefore to the same result as the technical considerations set forth in No. 433, in showing that the employment of steam is indispensable in the case in point.

If instead of 600 tons a day only 300 tons were raised, the manual labour would be almost the same as before, with the exception of the assistant hitchers, and their absence would reduce the daily expenses for wages from £1 16s. 8d. to £1 10s. 5d. (44 fr. to 38 fr.)

At the same time, more coal would be consumed in proportion to the output, say 3 tons instead of 4.

The ropes might last a little longer, say 15 months instead of a year.

The cost of keeping the engine in repair would not be reduced altogether in proportion to the smaller expenditure of power.

Having, finally, made every allowance, we should find that the cost per ton would be somewhere about 3¼d. instead of 0·199d.

(0·333 fr. instead of 0·212 fr.), or, we might say, 4d. (0·40 fr.) in round numbers, to make it comparable with the 2½d. (0·25 fr.) which we took before.

Thus in decreasing the daily output from 600 tons to 300 tons we increase the expense of raising each ton from 2½d. to 4d. (0·25 fr. to 0·4 fr.), or by 60 per cent.

(**469**) The foregoing figures make no allowance for redeeming the capital.

The amount of this capital, like the cost of winding the mineral, is not a sum which can be ascertained by an *à priori* calculation; and it should be made the object of a special investigation in each particular case. It is necessary to make a complete estimate by means of proper plans and specifications, and to take as the basis of calculation the usual prices of contractors and engineers for the different kinds of work.

Planning machinery of this kind is a matter of much interest, and one which is likely to draw out the full capabilities of the engineer who has charge of the work.

Merely for the sake of giving an example, we shall here mention the figures which M. Glepin brought forward as those of the cost of a large and very carefully-arranged establishment at one of the pits of the Grand-Hornu Colliery, 388 yards (355 metres) deep. Without counting the cost of the picking and screening appliances, nor that of the principal buildings; nor, in one word, that of anything but the plant we have been considering up to this point in connection with the service of winding; and keeping out even the price of the ropes, we arrive at a sum of about £4,000 (100,000 francs), distributed in the following manner:

	£	francs.
Winding-engine and boilers	2,852	(71,300)
Cages	108	(2,700)
Pulleys and mountings	76	(1,900)
Pulley-frame	136	(3,400)
Landing-place at the surface, &c.	260	(6,500)
Pit-bottom	160	(4,000)
Guides, &c., in the shaft	408	(10,200)
Total	4,000	(100,000)

We should think that, allowance being made for the present commercial crisis (1873), which exaggerates the normal state of affairs, the three first items would cost less, and the four last more, than the amounts given above.

Supposing now we wished to pay off this capital in ten years, it would be necessary to write off £400 (10,000 francs) annually, which would give a cost of 1·07d. (0·111 fr. per metric ton), with a daily production of 300 tons, or 0·535d. (0·056 fr.), with double this output.

Adding these new figures to those we obtained in No. 468, we shall find, finally, *in round numbers*, 3½d. (0·35 fr.) as the cost price per ton for raising the coal, based upon a daily output of 600 tons, and 5d. (0·50 fr.) in the case of an output of 300 tons; or, say 1s. 3½d. and 1s. 10d. per ton per mile (0·875 fr. and 1·25 fr. per ton per kilometre).

We will here make two remarks:

In the first place too much stress must not be laid on these last figures; we mean by this that they should not be employed as a basis for estimating the cost of winding from any other depth than the one now under consideration. Indeed, the depth is a *secondary consideration* in the cost of winding; and we should find, for example, that with a pit of 800 yards, and another of 200 yards, the expense would be much less than double in the former case, and much more than one-half in the latter, of the cost which we have found for a depth of 400 yards.

The second observation is, that the costs calculated above, namely, 3½d. and even 5d. (0·35 fr. and 0·50 fr.), should be considered *favourable* as compared with those which are often to be met with in practice.

We are, in reality, placed in very good conditions; namely, a large output, or, at all events, one above the average of pits at the present day; the whole output coming to the same pit-bottom, which is favourable to the manual labour; the absence of all trouble due to the use of kibbles; the vertical position of the shafts; and lastly, the employment of steam, in conjunction with cheap coal and a very perfect engine.

If these conditions were not *all fulfilled*, we should see the cost

mounting up progressively, in proportion to the disadvantages, until it attained 10d., 1s. 3d., 1s. 8d. (1 fr., 1·50 fr., 2 fr.), and more.

§ 2. Various details relating to winding.

(470) We have now described the essential machinery required in winding, properly so-called, together with the mode of handling it.

It may be said, in general, that winding is a most important service in any mine; and its importance increases as the intrinsic value of the mineral diminishes. It is requisite, therefore, to establish it under the best technical conditions, so that we may rest assured that the winding will be carried on in a regular manner, and, at the same time, as economically as possible. A stoppage of a few hours, or a day, is sufficient to cause considerable losses, as much from the actual deficiency in the output, as from the numerous expenses which have to be continued even during this accidental stoppage.

The engineers who make winding their speciality, have, therefore, closely studied the accessory arrangements required to obviate these troublesome detentions of the output, and many arrangements have been proposed, or are in use, which are designed to prevent one kind of accident or another.

We should not think of describing these arrangements in all their details; we shall simply point out the various kinds of accidents which it is desirable to prevent, or, at all events, of which it is wise to minimise the consequences; and we shall enumerate the arrangements which are recommended for that purpose, giving most attention to the principal ones.

We shall consider successively:

1. The means employed for maintaining a complete mastery over the engine, and being able to regulate its speed, or stop it at any instant.

2. The means employed for producing regularity in the coiling up of the ropes.

3. Those whose object is to prevent a breakage of the ropes

when they are exposed to abnormal strains, such as are produced by too rapid changes of speed, sometimes, for example, in lifting the cage off the bottom.

4. Those which are intended to prevent the cages from being raised to the pulleys, an accident which usually entails a breakage of the rope, or some other equally serious consequence.

5. The means employed to prevent the cage from falling in the event of the rope breaking.

6. Lastly, the various methods of communicating between the engine-man, the banksmen at the surface, and the hitchers; and the particular precautions taken to ensure the safety of the men.

(471) MEANS INCLUDED IN THE FIRST CATEGORY.—When the engine is going at full speed, the cages, in shafts provided with the newest appliances, are running with a velocity of 20, 30, or 40 feet per second; and it is said that a rate of even 49 feet has been attained (6, 7, 12, and 15 metres).

Even at this speed the engine-man should be able to pull up promptly. He should, besides, in every case, slacken speed during the three or four last turns which the engine makes before the full cage arrives at the surface, so as to have a thorough mastery over the engine, and be able to stop it in a small fraction of one turn of the drum.

For this purpose he makes use of the steam valve and the reversing lever, and by handling these he should be able to perform all the operations connected with bringing the cages to bank.

The lever can be moved in the same way as a locomotive lever, either by hand after the steam-valve has been closed for an instant, or by means of M. Marié's arrangement for reversing by means of a screw.

But the engine-man has likewise at his disposal a brake of sufficient power to stop the engine by itself, even with the steam full on. This brake ought always to be on when the engine is at a standstill, and in such a way that an untimely opening of the steam-valve cannot move the machinery. It should be released *by the engine-man himself* at the instant of starting; and it should

not be put on again until the engine has been once more brought to a standstill, unless under unusual conditions. This brake operates, as in most engines, by exercising a pressure on the rim of a wheel; a corresponding friction acting in the opposite sense to the rotation of the wheel is produced, and this gives rise to a strong resistance which impedes the engine.

The measure of the work produced in this way per unit of time is equal to the intensity of the friction multiplied by the speed of the rim.

The total friction depends only on the pressure; but the friction per unit of surface, whereby the surfaces in contact are worn away or heated, diminishes for any given pressure with the extent of the surfaces in contact.

Thus the conditions requisite for an efficient brake are—great pressure, a large area of contact between the rubbing surfaces, and a rapid motion of the moving surface. It is necessary that the brake should act instantaneously; and in order not to subject the axle shaft and bearings of the wheel to an unnecessary strain, it should act either at points diametrically opposite to each other, or over the greater part of the circumference of the wheel in such a manner that the normal pressures counteract each other, while the tangential forces are reduced to a couple.

The various conditions enumerated above are realized when the rim of the fly-wheel is taken for the moving surface; when it is seized between two jaws or blocks, each of which occupies a certain arc on its periphery, situated nearly diametrically opposite to each other; and lastly, when these jaws can be drawn tightly towards each other by a system of rods and levers connected with the piston of a small steam-cylinder. Whilst the steam is not acting on the piston of the brake-cylinder, its interior is kept at the same temperature as that of the steam in the boilers, so that it may be made to act instantaneously when steam is turned into it.

Figure 365 represents a brake of the kind described above, which looks perhaps somewhat rough, but may be considered to be well adapted for the work.

Figure 366 represents another, which, although presenting

perhaps a more satisfactory appearance to the eye, does not appear to us to present any marked advantage over the preceding one.

The action of the steam is sometimes replaced by that of a counterpoise, which the engine-man can bring into play by moving a special handle.

There are also some arrangements for tightening the jaws of the brake by hand; for example, by means of a handle, which turns rods with threads cut on them. This system enables the pressure to be increased gradually with less chance of injuring the machinery; but it has the disadvantage that the brake cannot be applied instantaneously.

We believe that for a winding-engine a steam-brake is to be preferred.

As a rule, as we have already said, the brake is *on* when the engine is at rest. The interior of its steam-cylinder ought therefore during all this time to be in communication with the steam in the boilers, in order that the steam contained in it may not undergo condensation.

In order to avoid an accidental slackening of the brake, which might chance to occur if its steam-valve were accidentally shut off at the wrong time, thereby permitting the steam to condense in its cylinder, we may employ a special arrangement, which, when once the brake-lever is in the position in which it acts, maintains it constantly in that position, even when the steam ceases to act on the piston. It is only necessary to have a strap connected with a rod with a thread on it, working in a long nut provided with a small hand-wheel. On turning the nut from right to left, for example, the lever is left free to move; but on turning it in the opposite sense the lever is fixed in such a position as to keep on the brake.

In the case of engines worked with toothed gearing, which are still sometimes used, it would be prudent to have two distinct brakes—one of them to be used regularly, and acting on the rim of the fly-wheel; the other to be used in case of accident only, acting on a special brake-wheel, keyed on between the drums, and employed to stop the drum-shaft directly.

We may here remark that the employment of counter-pressure

of the steam affords likewise a very energetic brake, if it becomes necessary to stop the engine quickly when it is working at full speed; but it does not dispense with the ordinary brake, which should always be on when the *engine is at a standstill.*

(472) Means included in the second category.—Flat ropes always coil regularly on their drums.

The same is the case for round ropes on a cylindrical drum, if it is so narrow that a rope stretched between any point of it and the pulley can be considered to occupy almost constantly the same position.

With a slightly conical drum the conicalness itself contributes to the regularity of coiling, or to the exact juxtaposition of the successive coils, in consequence of the tendency which the rope has, under the action of the load, to wind itself upon the smallest possible radius.

This is not the case either with a horizontal drum, which is too long or too near the pulleys, nor with any vertical drum.

But a round rope can always be compelled to pass through a given point, and to bend at that point in any direction that may be desired. It is only necessary to place a sheave or pulley at that point, having its plane coinciding with that contained between the two branches of the rope; and if it is necessary to keep the rope in the groove of the pulley, this can be done by means of another sheave tangential to the first. (Fig. 367.)

If this arrangement is to be applied for the purpose of regulating the coiling of the ropes, it is only necessary to make it movable, and to arrange that it places itself suitably at every instant to each rope, both in point and direction.

For this purpose the two sheaves are fixed to the same frame, which moves in a slide parallel to the axis of the drum, and advances during each revolution by a quantity equal to the diameter of the rope; in this way, during any two consecutive revolutions, the rope is compelled to coil in exact juxtaposition.

In order to move the frame which carries the sheaves, a spindle, whose circumference is the same as the diameter of the winding rope, is fixed to the drum-shaft. This spindle winds and unwinds

a cord which is attached to the frame after passing over a pulley placed in a suitable position. The cord is entirely wound on when the rope is wound off, and *vice versa;* it draws the frame in one direction, while a balance-weight draws it back again.

This ingenious arrangement is especially applied to the vertical drums of horse-gins, used for winding, when they are far from the pulleys, and when the rope is not kept sufficiently stretched in the intervening space.

Figure 368 gives an idea of this contrivance. Sometimes it is replaced by a simple roller, which may either be on a fixed or loose axle, and is balanced like the roller for stretching a belt.

Several of these rollers may be put in between the drum and the pulleys if the distance is too great. They are applicable to both flat and round ropes.

(473) MEANS INCLUDED IN THE THIRD CATEGORY. The means of preventing the accidental breakage of a rope in use consist principally in working the engine carefully, and avoiding sudden changes of velocity, especially at the moment of lifting from the bottom.

It has already been remarked, in No. 454, that when *the engine is running in a regular manner* the accelerated motion of the ascending cage, and the retarded motion of the descending cage, do not sensibly differ from a uniform motion when flat ropes are employed, and, consequently, the tension on the rope during these movements may be regarded as being the same as when it is at rest.

This is true on the supposition of a constant angular velocity of the engine, which gives $\frac{d\omega}{dt}=0$.

But it is not the case during the period of acceleration which succeeds the starting of the engine. In reality the velocity of the cages is obtainable, as we said in No. 454, from the formula $(\rho \pm me)\omega$; but the complete differential referred to time is $(\rho \pm me)\frac{d\omega}{dt} \pm e\omega\frac{dm}{dt}$; or, replacing $\frac{dm}{dt}$ by its value:

$$(\rho \pm me)\frac{d\omega}{dt} \pm \frac{e\omega^2}{2\pi}.$$

At starting, where $m = 0$, this quantity is:

$$\rho\frac{d\omega}{dt} \pm \frac{e\omega^2}{2\pi}$$

and we cannot regard it as very small if $\frac{d\omega}{dt}$ has a high value.

It is obvious that, in starting from the bottom, there may be a considerable strain on the rope at the point where it is, or begins to be, coiled on the drum, besides what is due to the weight to be lifted; and this arises from the acceleration which it is necessary to communicate to the mass, consisting of the useful weight, the dead weight, the whole rope, and, strictly speaking, also the pulley.

It is necessary, therefore, that the engine-man should take the precaution to start slowly. The rope begins to move while the cage still rests on the catches at the bottom, and stretches itself gradually; and it is only when it commences to lift the cage that the engine-man sets off the engine quickly.

The preservative influence of this stretching of the rope can be augmented by two devices. The one which M. Guibal proposed was to have the pulleys resting on an elastic support. This was to produce an effect similar to what would take place if the rope stretched further of its own accord. Besides, the pulley-frame itself is preserved from the blow of a battering-ram, as it were, which it sustains when the two ends of the rope are strained too abruptly. It is evident that any excess of tension of the rope, produced in any way whatever, reacts on the axle of the pulley; for the resultant of the two component forces, which always act in the same direction, increases in amount in proportion as the two components are augmented. This arrangement, which is not perhaps so often employed as it ought to be, is represented in figure 369.

As an additional arrangement, it has been proposed to take advantage of the small movement of the spring, which takes place when the rope is unduly stretched, for the purpose of giving some kind of signal, such as ringing a bell, for example. The object of this is to avoid over-stretching the rope, either when the cage encounters some obstacle, or if the engine-man starts too abruptly.

It could even be arranged that the steam should be cut off from the engine, by means of a similar contrivance, and turned into the cylinder of the brake. But it seems to be a delicate matter to utilize the movement of the spring, which is necessarily small and variable in amount, and this arrangement does not appear to have been adopted by many people.

The second device, which is much employed in England, is to interpose a spring between the end of the rope and the load. As far as regards the inertia of the cage this system is satisfactory, and it is especially applicable with wire ropes, which are less extensible than those made of hemp or aloe fibre; but it is incomplete in so far as it does not affect the inertia of the rope itself, whose mass is, as we have seen, comparable to some extent with that of the load.

These springs can be arranged in various ways.

Figure 370 shows the application of a spiral spring made of steel, enclosed in a box, which is shortened more or less under the action of the load. Indiarubber springs are also employed, and they are arranged much in the same way as those used in the buffers of large railway waggons.

(474) MEANS INCLUDED IN THE FOURTH CATEGORY. The first means for preventing the engine-man from drawing the cage over the pulleys, is to provide an arrangement for enabling him to know either the exact position of the cages in the shaft at any moment whatever, or, at all events, when the ascending cage comes within a certain distance of the top, so that he may be able to slacken the speed of his engine, and prepare to stop it entirely. A simple method of effecting this object is to paint a white mark on the rope at a certain height above the cage; and when the engine-man sees it emerge from the pit-mouth he knows it is time to commence to slacken speed. It may even be sufficient in some cases to attach a piece of chain to the end of the rope, of such a length as to give the engine-man time to pull up when he sees it appearing at the surface. (A chain applied in this way has also the additional advantage that it prevents the rope from bending when the cage rests on the bottom.)

The system of having marks on the rope is quite sufficient when there is only one hanging-on place, and when the rope is well under the engine-man's eye during the day-time, and properl lighted by a reflecting lamp at night.

Another means, which is more complete, and indicates the position of the cages in the shaft at every point of their course—when they pass each other, when they arrive at a hanging-on place, &c., &c.—is to apply the system described above in connection with regulating the coiling of ropes (No. 477). In this case the spindle may be made of any diameter, provided that the length which the cord travels does not exceed the height of the engine-house. A vertical line is drawn on the side of the engine-house to represent the shaft, and the cord causes a small weight, which represents the cage, to pass up and down on it. In the same way both cages can be represented if desired by small pieces of wood or iron attached to an endless cord, which passes over two pulleys, one of which is put in motion, in one sense, by the cord described in the last paragraph, and in the opposite sense by a counter-weight.

All these arrangements are easily carried out, and we need merely mention them. This small apparatus may be further completed by adding a bell, which is made to ring when the travelling indicator, which represents the cage, is approaching the end of its course, &c.

There are some other contrivances which are rather more complicated than the one just described, but also more sure, because they are not, like it, at the mercy of the first comer who happens to enter the engine-house.

They generally consist of an endless screw, which is made to revolve by means of a pair of small mitre wheels connected with the drum-shaft.

This endless screw carries one or two travelling blocks, or nuts, which move at the rate corresponding to the pitch, or it may be geared into a worm-wheel, which advances by a distance equal to one tooth for every turn of the screw.

It is easy enough to arrange that either the travelling blocks, or nuts, or studs suitably placed on the worm-wheel, can be made to

ring bells at any desired point, or that they shut the steam valve, or put on the brake, &c.

The travelling nuts can also be made to act upon a counter each time a cage is raised to the surface, so that at the end of the day's work a record is obtained of the number of complete journeys the cages have made in drawing mineral, and in other services that may be necessary, such as raising and lowering men, letting down timber, &c.

Figure 371 gives two examples of arrangements of this apparatus. In one the endless screw is made to move two travelling nuts; in the other it actuates a worm-wheel with studs. (See the description of the plates.)

If we supposed that these various signals were insufficient to attract the attention of the engine-man, and that there was still danger of the cages being drawn up to the pulleys, we could again, in view of such an unlikely occurrence, take certain further precautions.

We might, for example, place the pulleys on the top of the frame in such a way that the cages would pass up over them without coming into contact with the woodwork, and being thereby forcibly stopped. This arrangement, which is shown by the type of pulley-frame represented in fig. 348, admits of the cage passing over the pulley without breaking the rope. The only consequence is the breakage of the cage itself, which falls to the ground from the top of the pulley-frame.

Besides the system described above, there are a whole multitude of apparatuses known as *contrivances for preventing overwinding*, the object of which is to prevent the cage from reaching the pulleys at all, and much less to facilitate its passing over them.

Thus, for example, an elastic stop or buffer can be placed at the height to which the cage is allowed to ascend, and against which it may strike and be brought to a standstill, with some chance that the rope may not be broken. A better system is to have the guides coming gradually closer together above the landing at the top of the shaft, so that the cage, in being drawn upwards, gradually wedges itself more and more firmly as it ascends. It acts like a very powerful brake, but more gradually than the buffer, and con-

sequently with less chance of a breakage of or damage to the rope. It is in general necessary to avoid a breakage of this kind, which is not without inconvenience even after it has been repaired; for it is well known that every piece is weaker after a breakage than before, in consequence of its limit of elasticity having been much surpassed.

It may be arranged that, at the same time as the cage wedges itself by the gradual convergence of the guides, the cage and the rope become disconnected.

This problem can be easily solved in several ways.

We can, for example, fix a ring to the frame through which the rope can pass, but of such a diameter that it forces together the two branches of a fork like that used with a pile-driver. The forcing together of these branches can be made to break a pin which disengages the ring at the end of the rope. (Fig. 372.)

This disengagement can be effected by the curvature of the pulley, by having a piece of flat chain at the end of the rope. (Fig. 373.) This method is only applicable with a flat rope.

We can also employ, with a flat rope, a stop standing out from the back of it. On being wound up a little further than usual this stop acts upon a system of levers, which shut off the steam and put on the brake.

All these systems include, as may be easily imagined, a large number of variations, into the details of which it is not necessary to enter, even if space permitted us to do so.

(475) Means included in the fifth category. The breakage of a rope, if not provided against, produces, or tends to produce, the gravest consequences. Not only is the cage which falls down the shaft completely smashed, if it drops a considerable depth, but the guides themselves may be driven out of their true position to a greater or less extent, and the catches at the bottom may be destroyed like the cage.

Besides, if the breakage takes place near the pulleys, while the cage is still at a considerable distance from the surface, the latter drags after it a length of rope which lashes against the sides of the shaft, and may knock away the guides and brattice, or casing, or

completely destroy them. On arriving at the bottom, moreover, it piles itself up closely, and wedges itself together in such a manner as to receive much injury, and be most difficult to disentangle.

We do not speak of what happens in such a disaster if the cage contains men.

These are the various consequences which we may endeavour to avoid or mitigate.

If the cage is separated from the rope by the action of a safety contrivance which disengages it, we may imagine that it remains suspended if it is sufficiently firmly wedged between the converging guides, or else falls back from a small height upon the catches at the surface, which we shall suppose to be arranged so that they shut automatically as soon as the cage has passed through them.

It will be safer, however, to have a special set of catches placed immediately below the point where the cage is released by the detaching apparatus, so as to arrest its motion *at once*, and before it has acquired a sensible downward velocity. This point is well known and accurately fixed.

These auxiliary catches, which will seldom be called into play, should have a means of shutting them after they have been opened by the passage of the cage. For this purpose a spring or counterweight should be employed of sufficient power to overcome the effects of rust or dirt.

If the cage is separated from the rope by a breakage, at any point whatever, it ought to be arrested in the shaft; and the apparatus employed for this purpose constitutes what is called a *safety cage.*

Safety cages may be looked upon as objects of considerable importance. They deprive accidents of this kind of their serious character, and admit of the ropes being kept longer in use, which are otherwise, from a feeling of prudence, often taken off and replaced by new ones, after they have been in use for a certain period, or after a certain quantity of coal has been raised by them, although they may still be in a state of perfect preservation.

At the Great Exhibition in London, in 1851, there were many models of this kind of apparatus, which began to be largely used

about that time in the Newcastle coal field. About the same time also they were used in the Decize mines, in France.

At the present day they are very largely employed. They are constructed in very various ways, and during the last twenty years many of the forms have been patented. In reality, however, they all depend on one and the same fundamental principle, and the various patents differ only in the details.

It is true, all the same, that, the principle being given, the value of an apparatus depends upon the details and the manner in which they are carried out, and that, in many cases, a slight modification is sufficient to make an apparatus safe and reliable, which would otherwise be of doubtful utility.

The principle which is common to them all is to introduce some kind of elastic medium between the cage and the rope, which is capable of being pressed together, as far as it will go, by a weight somewhat lighter than that of the empty cage. It is, of course, inoperative so long as the cages, either full or empty, are suspended by the rope, or receive no *sudden* variations of speed, whether *positive* accelerations which diminish for an instant the action of the descending cage, or *negative* accelerations which diminish that of the ascending cage.

If the rope breaks the elastic medium comes into play, and actuates special contrivances which clutch the wooden guides and so arrest the cage. The effect of these contrivances is particularly efficacious in the case of an ascending cage (which is the most important case), because this cage, before beginning to fall under the action of gravity, gradually loses its ascending velocity and comes to rest, and this gives time for the apparatus to come into play and produce the required effect.

The most usual method of obtaining this effect is to force sharp arms into the body of the guides, or to compress them firmly between excentric clutches.

It is the weight of the cage itself which forces the sharp arms into the wood, or causes the excentrics to act; and the resulting resistance is, therefore, in proportion to the force that has to be overcome. In our opinion the action of the excentrics may be considered to be more sure than that of the sharp arms; and it is

better to apply the force to the sides of the guides than to their front, as the latter system tends to displace them, and makes it necessary to have them very firmly and solidly fixed.

There are, however, some kinds of safety cages in very common use, and considered to be very good, in which the last conditions are not fulfilled.

(476) We shall confine ourselves to pointing out a few of these apparatuses. There exist perhaps over fifty varieties of them, and it would not always be an easy matter to point out any characteristic difference between some of them.

One of the first which was largely used, especially in the north of France, was that of Fontaine. It is shown in figure 374. It acts by means of levers, which are thrust into the front faces of the guides by a spiral spring, which comes into play when the rope breaks. It presents therefore the two objections which have just been pointed out above; but nevertheless its details have been well carried out, and experience has shown that it acts properly.

It will be remarked that a single suspending rod and a single spring would be sufficient to cause the arms to act.

The first apparatuses were constructed in this way; but it is preferable, on the ground of greater safety, to make the two arms independent, so that each of them may take the proper amount of movement which it ought to have in order to force itself into the corresponding guide, in the event of the cage not being placed quite symmetrically in regard to the two guides.

Figure 375 represents the safety-cage employed at Blanzy. It acts by the play of two spiral springs arranged in much the same way as those in Fontaine's apparatus; but they actuate excentric clutches, which seize the guides laterally. The surface of these clutches is ribbed, in order to increase their friction.

Figure 376 represents Libotte's safety-cage, in which the action of the excentric clutches is produced by a spring composed of superposed plates of steel instead of the spiral spring of the preceding apparatuses. It is largely employed in Belgium and the Ruhr basin.

Lastly, figure 377 represents M. Micha's safety-cage, which is in use at the Marles mines (Pas de Calais). It is well designed, and acts efficiently.

We will add an example of another kind of *safety-catch.* It acts under conditions which are essentially different from the foregoing, and is employed at certain mines where the winding is still carried on by means of chains, and notably in Cornwall. This system, which is represented in figure 378, is applicable only to the ascending chain, the one which is at the same time most exposed to breakages. It consists in making the chain pass through a slit, one of whose faces is fixed, while the other is formed by a kind of small shutter, which is lifted by each link which is not parallel with the slit.

At the instant a breakage takes place, the first backward movement is checked by the shutter, which prevents a downward movement of the chain.

(477) Means included in the sixth category.—Some means of communication ought to be established between the engine-man and the workmen who are engaged both at the top and bottom of the shaft.

With the banksmen, the most easy and certain means of communication is the voice, the distance being usually very short. The engine-man ought also to be placed in such a position that he can always see the ropes, and is not obliged to follow any signals blindly, without having first assured himself by a glance at the top of the pit that all is right.

With the hitchers again the voice can be used as a means of communication, if the pits are not more than 200 yards deep, and if they have been sunk through rock, or are walled throughout; but with timbered pits this method is inadmissible at such a depth.

When the voice is not applicable, the ordinary method is to have small bells, which are rung by means of wires, or, better still, by small wire-cords, which traverse the shaft from top to bottom.

These wire-cords are balanced by a weight at the surface; and

if the pit is very deep, they may have several counterpoises at regular distances apart in the shaft.

They are actuated by pulling, at the bottom of the shaft, either directly or by means of a lever, to which they are attached.

The signals are more easily understood where, instead of ordinary bells, a hammer striking on a plate or bell is employed, making only one sound for each movement of the lever. The message to be conveyed is signified by the number of strokes, and sometimes by the rapidity with which they succeed each other. They vary from 1 to 4. When men are to be raised, several rapid strokes are given as a preparatory signal. The engine-man ought then to be more than ever on the alert. He should wind rather slower generally, and the chief banksman ought to attend at the top.

It is urged against these signals that they can give only a very limited number of indications of what is wanted, and that they are exposed to interruptions arising from an accidental breakage of the cord.

It may be replied to this that there is no necessity for very various signals, and that if the wire is properly fixed it ought not to break. The advantage possessed by it, on the other hand, is, that by its means a signal can be given from any part of the shaft between top and bottom, if it is within reach of the men in the cage, as it ought to be, when they are examining or repairing the shaft.

It has been proposed to replace this system of signalling by various arrangements, sometimes by introducing speaking-tubes, which permit the distance at which the voice can be heard to be increased; sometimes by metallic rods, made quite continuous throughout their entire length, and transmitting from one end to the other any signal made by striking them with a hammer; sometimes by the pneumatic signal, which is used in many large hotels and other similar establishments for sounding a whistle or ringing a bell; sometimes by the system proposed by M. Harzé, which consists in filling the tubes of the preceding apparatus with water, and then acting upon it by means of a piston making the water-column transmit oscillations from one end to the other, which are made visible by a long needle on the face of a dial;

sometimes, lastly, by the electric telegraph, which can be employed with all its arrangements for transmitting any required signals from the bottom of the shaft to the engine-man.

By applying a plan devised by M. Mathieu, of Douchy, we can obtain with electric wires the same advantage, of being able to signal from any point in the shaft, as that possessed by the signal-cord. For that purpose two wires connected with the bells at the top are fixed along one of the guides, and the person who happens to be in the cage is provided with a kind of fork with a handle. The two branches of the fork can be applied to the two wires simultaneously, and in this way, the circuit being closed, the bell rings.

We think that the electric telegraph applied in this way is preferable to tubes, because the latter cannot transmit signals except from their ends.

On the other hand, however, the manipulation of electrical apparatus is perhaps too delicate an affair for men who are making great muscular exertions all day long like the banksmen and hitchers, and the apparatus runs much risk of injury at their hands. We think that it would be advisable to have a special signalman for the purpose.

It appears to us that the employment of the electric telegraph is amply justified when communications have to be made in an intricate network for the purposes of underground haulage, for example, along several branches; but it is much less required in a vertical shaft, where the signal-wire is stretched in a straight line from one end to another, and the only signals that have to be made are those between the bottom and the engine-man. In this case the ordinary system of having a signal-wire is probably the most satisfactory that can be adopted.

(478) Accidents of various kinds may overtake the engine-man, or the men at the top or bottom of the shaft; or, lastly, the men who are being raised or lowered in the cages. The engine-man should be placed out of the reach of injury from the end of a rope, which might spring back to the drum in the event of a breakage.

In this respect he is safer with an ordinary horizontal engine having the drum between himself and the pit than with a vertical engine, or a horizontal one, in which the cylinders are placed between the drum and the pit for the purpose of having them near the shaft, or of diminishing the angle made by the ropes in passing over the pulleys.

For the banksmen, the chief danger, with which they become too familiar, is that they may fall into the pit. It is highly desirable that the mouth of the shaft should be kept completely enclosed at all times, partly by a fixed fence, and partly by a movable one, which can be opened when required. The fence may be opened either by the men, or automatically by the cage when it comes to the surface; and in this manner the mouth of the pit is always guarded either by the fencing or by the cage.

When men are in the cages, the engine-man, having been previously warned, is very careful to run at a moderate speed, and to set down the cage both at the top and bottom of the pit as gently as possible. The supports on which the cage rests at these two points are sometimes rendered elastic by means of india-rubber springs. The long sides of the cage should be made of a lattice-work of iron to prevent any of the men from putting a limb outside inadvertently. It should be closed in on the top by a strong cover of sheet-iron to prevent the men from being struck by stones that might fall away from the sides of the shaft, or by the end of the rope if it broke.

When men are to be raised, the cage should not be lifted off the bottom until a special signal has been given after all the men have taken their places in it. Sometimes also, for the purpose of preventing a premature departure of the cage, it is held in its place at the bottom by bolts, which are not withdrawn until the signal is given, &c.

(479) Such are the principal arrangements which appear to us to be worth mentioning here. We do not pretend to have described the whole of them, but an account of others may be found in special publications, such as those of M. Burat, and in M. Ponson's treatise and supplement.

These arrangements have been, and still are, the object of much study and many experiments, and, as may be imagined, they can be varied almost indefinitely as regards their special details and the manner of putting them in action, though not of course as regards the results to be obtained.

We will add that it is possible to go too far in multiplying the number of automatic appliances. This has been to some extent the case in mining as in railways, for which many inventors have sought to increase the number of safety appliances and warnings destined to come into action when some abnormal circumstance arises.

In increasing the appliances in this way there is a tendency to produce a want of attention on the part of those who should be on the look-out; they trust to the action of the apparatuses, which may break down at the very moment they ought to act. These very appliances then become the cause of as serious dangers as those they were intended to avoid, since their employment has had the natural effect of removing the feeling of responsibility from the persons in charge.

In our opinion it is not necessary to strive to refine too much in affairs of this kind. However ingenious an apparatus may appear to be, or even for the very reason of its being *too ingenious* and *complicated*, it would be of less value to the engine-man than the information he would be able to get by using his own eyes.

Thus, for example, if the question is to give notice of the approach of a cage to the surface when men are being raised, the best, and in our opinion the simplest, plan is to have a distinct mark on the rope, and to arrange for a verbal signal from the banksman, who should always be at his post in such a case.

For the purpose of communicating between the banksmen and the engine-man nothing can be better than the voice, assisted, if necessary, by a speaking-tube, having its end attached to one of the legs of the pulley-frame within reach of the banksmen. Nothing can be better for the signals from the bottom to the top than a strong signal-cord, by means of which a hammer can be made to strike a bell which emits a special and distinctly characteristic sound.

With these appliances, completed by a powerful brake, a good safety-cage, such as those of MM. Fontaine and Micha, an arrangement for preventing overwinding, like that obtained by converging guides, and a cage affording due protection to the persons in it, the engine-man will be more attentive and more master of himself than if he were bewildered, as it were, by a multiplicity of warnings of different sorts; and we believe that, as far as safety is concerned, the conditions may be considered as satisfactory as prudence could wish us to make them.

CHAPTER XVIII.

MEANS OF DESCENDING AND ASCENDING MINES. DIGRESSION ON WINDING FROM ANY DEPTH.

(480) We devote an entire chapter to the description of the means adopted for ascending and descending mines; for although they may be very simple in the case of shallow workings, it may be quite a different matter where the mines are very deep.

The work of descending and ascending mines by means of steps or ladders becomes more and more laborious for the men as the depth increases, and it is the interest of the owner to provide suitable machinery to do the work for them.

It is his interest to do so on the score of the cost of labour, because the men are naturally obliged to reserve time and strength for making the ascent and descent, and the work they can do underground is proportionately reduced.

Thus, for instance, in a mine 550 yards (500 metres) deep, it is reckoned that it takes *more than an hour* to climb up, and *half-an-hour* to go down. The possible day's work of a man is thus diminished by an hour and a half, and this time is employed at a task which is more laborious than his ordinary work. The loss of useful effect is, therefore, more than proportional to the time occupied in making the descent and ascent.

At 900 yards (800 metres) this time would be at least doubled, and it would become practically impossible to carry on a mine under such conditions.

This is just as much a question of humanity as of economy; for it is only young and vigorous men who can support the fatigue of making long descents and ascents, and even their health is

quickly injured. Their respiratory organs suffer from the exertions they undergo, as well as from the sudden changes of temperature to which they are exposed on arriving at the surface, panting and soaked with perspiration. After they have acquired a store of useful experience, they are obliged to leave off working in the lower levels, where they would be most useful, and they have to confine their labours to the shallow parts of the mine, or else have to give up underground work altogether when they have only reached middle age.

In deep mines, therefore, machinery becomes quite as much a necessity for raising and lowering the men as it is for winding the mineral. Indeed, at exceptional depths, exceeding 450 to 500 fathoms (800 to 900 metres), which have been already reached in some coal and metal mines, it is even *more* necessary, because where a small output will suffice, winding by animal power is after all a mere matter of cost. On the other hand, very few men *would be found* willing to earn their living in such a painful manner, at all events in a country where there were many other openings for labourers.

(481) The simplest methods of ascending and descending mines are by walking or climbing. A path may be made from the outcrop, or from an adit level, down winzes sunk along the dip or carried diagonally. As long as the slope of the gallery does not exceed a few degrees it can be ascended or descended without any special arrangement, and without any other difficulty than that of occasionally meeting with ground rendered slippery by constant wear, especially where there is running water and a hard fine-grained rock.

Above 30°, which is about the angle of an ordinary staircase, it would not be possible to walk up and down without steps; and these may be cut in the rock, or made by means of pieces of wood put across the gallery.

When we come to an angle of 45°, which exceeds that of most of the slopes of any extent met with at the surface, we find it very laborious work to go up or down. For angles above this, and *à fortiori* for those we have to deal with in vertical shafts, we have

recourse to ladders. Ladders are usually made of two parallel side-pieces of timber, 4 to 4½ inches by 1¼ to 2 inches (10 to 12 centimetres by 3 to 5 centimetres), the greater dimensions being at right angles to the plane of the ladder.

The staves or rungs are also made of wood, and are fixed 8 to 10 inches ($0^{m}{\cdot}20$ to $0^{m}{\cdot}25$) apart from centre to centre. Sometimes they are made round, sometimes flat, and widest in the middle. This latter form gives additional strength, and renders them more convenient for grasping.

Wooden ladders answer perfectly well where the men go down barefooted; but they wear out rapidly, and require constant repairs, if the miners wear wooden shoes, or shoes with nails. In cases of this kind it is probably more economical, in spite of the higher original cost, to use iron ladders, which are far more durable.* The side pieces are made of flat iron 2¼ to 2¾ inches by ¼ inch thick (6 to 7 centimetres by 6 to 7 millimetres). The staves are of round iron about an inch (25 to 27 millimetres) in diameter.

In a vertical shaft the *footway* is usually fixed in a small compartment, separated by a partition from the portions used for winding and pumping. The partition may either be partial or complete (*close casing*), and it is sometimes made air-tight when a special air current, distinct from that of the rest of the pit, has to go through the compartment in question. We shall speak of this further on, under the head of ventilation.

It sometimes happens that ladders are fixed vertically without any break for considerable depths. This arrangement ought to be *prohibited absolutely* † in a regular footway, we mean where ladders are fixed permanently to serve as the daily *travelling road* of the majority of the men. Vertical ladders should be allowed only in very special cases; for instance, in a pumping shaft, where they are merely used by the men who have to look after the pumping machinery (*pitwork*), and even here it is advisable to have a plat-

* In Cornwall the sides of the ladders are made of wood, and the staves, as a rule, of iron, and fixed from 10 to 12 inches apart; in the Hartz the ladders are sometimes constructed with iron sides and flat oak staves.—*Translators.*

† In the United Kingdom it is illegal to fix the ladders in a vertical position. *Translators.*

form (*sollar*) at the foot of each ladder. They may also be necessary during sinking operations, before the shaft has been divided into compartments, and in this case the bottom ladder should be made of iron to resist the effects of blasting. Very often the sides are formed of as many pieces as there are staves, and the ladder being thus rendered flexible can be drawn up if necessary before firing shots.* These ladders are fastened at the top and hang loose at the bottom.

Climbing vertical ladders is most laborious work, because the body is overhanging, and because it is necessary to draw one's self up by the arms, besides raising one's self by the legs. These ladders are also very dangerous, because if a man from any sudden weakness were to loosen his hold he would be liable to a fatal fall. Besides all this, his fall would endanger the lives of all the men below him, if the accident were to happen at relief-time, when there were a number of men in the footway. Therefore even in a narrow compartment the ladders should *neither be too long, nor too steep.*

Of these two elements, length and inclination, the latter is by far the more important. The angle should be such that if a man stands upright on the ladder with his elbows close to the body, and the forearm somewhat extended, his hand should naturally catch hold of the proper stave. His hands merely serve to steady him, and have no particular strain thrown on them. Practice shows that this angle is about 70° from the horizontal. This practical datum has been fully confirmed by M. Lambert's experiments on the subject. He measured with a dynamometer the strain exerted by the hands on ladders at different inclinations, and he found that it was at its minimum when the angle was 70°; as the inclination increased the strain rose very rapidly, and on nearing 90° it exceeded *half the maximum* effort that a man can exert momentarily. Ladders fixed in a position approaching the vertical are very tiring.

On the other hand, smaller inclinations are also fatiguing, *even for the arms*, because they have to support part of the weight of the body when it leans over much; and also for the legs,

* In Cornwall, and elsewhere in England, *chain ladders* are used, the sides being made of chain, and the staves of round iron.—*Translators.*

because a man has to go over more ground to raise himself a given height.

The ladders from sollar to sollar may be fixed either *all parallel*, or so as to form alternating series inclined in opposite directions.

In the first case, we suppose the ladders fixed on one side of a compartment; the miner on arriving on a sollar moves sideways, and walks straight across to the opposite side, where he finds the next ladder in front of him, and the *man-hole* through which he must descend.

In the second case, the miner, on reaching the foot of the ladder, has to turn round on the sollar in order to find the next ladder and the man-hole.

We have no hesitation in saying that we consider the plan of having the ladders parallel, as shown in figure 379, to be preferable to the other. It is true that this system requires a *somewhat wider* compartment, and this may at times occasion a slight difficulty; but, on the other hand, the compartment *need not be so long* for a given distance between the platforms.

Besides, it affords more safety, because the distance through which a man might fall is limited to the height of one ladder. With the other arrangement, on the contrary, if a man loses his hold, and slips down the ladder, he drops on to the platform at the very brink of the man-hole, and is very likely to fall through it. In order to prevent accidents of this kind as much as possible, as well as to secure convenient places for the men to pass each other in going up and down, the sollars should be made *as large* as possible, and the man-holes only just big enough to let a man through them.

One complaint sometimes urged against the use of parallel ladders is that a greater distance has to be traversed, as you do not pass directly from one ladder to another. This however, in our opinion, is an advantage, because it causes a change of position, and brings other muscles into play, and thereby tends to diminish the fatigue.

Parallel ladders should be so arranged that the miner should always pass on one particular side when going to the next ladder. It is also advisable that every detail should be repeated in identi-

cally the same manner, such as the length and slope of the ladders, size and position of the man-hole, &c. This uniformity facilitates *travelling* up and down the shaft. The men soon go through every motion mechanically, as it were, and they are not afraid to go on climbing up and down if their lamps are accidentally blown out.

Ladders should be firmly fixed at both ends by strong staples; and where two ladders are joined, it is advisable to put in a sleeper. The whole should be quite rigid, and it should not vibrate under the weight of the men. If this point is not attended to oscillations ensue, which become very fatiguing. Oscillations also are apt to destroy the sense of safety, and they render it more difficult for one to notice the state of repair of the ladders while climbing.

The platforms are made of planks; or, if the compartment has to serve for ventilation, open or lattice-work can be used, as shown in figure 379. This lattice-work is generally made of wood; but of course an iron grating may be employed if desirable, and then the ratio of the open to the closed part is very much greater. This constitutes a great advantage in favour of iron with regard to ventilation, as it is equivalent to increasing the size of the compartment; but the surface of iron *sollars* is more slippery, and less comfortable for the men.

The maximum distance between the platforms in each case is determined by the two conditions—that the ladder should be inclined, as we have already said, at an angle of 70°; and that its projection should be rather shorter than the length of the compartment. This distance varies from 4 to 5½ fathoms (7 to 10 metres). There is no advantage in having it more than 5 fathoms; but it is rarely much less than 4 fathoms, so as to avoid having too many sollars. The stipulation that the ladders shall be properly inclined is, however, far more important than the question of having a few sollars more or less.

If the compartment were so cramped that, even with parallel ladders, the number of sollars would become preposterous, we might think it a good plan to substitute spiral ladders with a uniform slope of 70° for the vertical, or nearly vertical, ladders.

This arrangement has been proposed, but has never made much way in practice. The fact is, spiral ladders are more complicated in their construction, and more tiring to climb than straight ones. We can form some idea of this inferiority if we compare in our own minds the difference in comfort of going up a wide staircase and a spiral one coiled round a small core. We should not hesitate therefore to prefer ordinary ladders, and all new shafts should be sunk sufficiently large to allow of a good *footway* being put in.

(482) Some mechanical substitute for ladders, which is *very desirable* for depths exceeding 100 fathoms (200 metres), becomes *almost necessary* at depths of 250 to 275 fathoms (450 to 500 metres), and *absolutely indispensable* beyond 300 to 450 fathoms (600 to 800 metres).

We shall be able to realize this better if we remark that in climbing the best arranged ladders a man is in the same condition as if he were walking on a tread-wheel. We know that in this case he can produce a useful effect of 1,880,000 foot-pounds (260,000 kilogrammetres, *Cours de Machines*, No. 39), or lift his own weight vertically about 2,200 fathoms (4,000 metres). As a rough estimate, we may admit that the fatigue of going down is about half that of climbing up; the descent and ascent of a shaft 450 fathoms deep would correspond to an ascent of 675 fathoms, say $\frac{675}{2,200}$, or 30 per cent. of the maximum amount of power that a man is able to exert in a day's work. In other words, by sending men to work at a depth of 450 fathoms we should lose *much more than* 30 per cent. of their labour. When we look at the question in this light the inadequacy of ladders is very evident, and we see the necessity of having recourse to mechanical means.

The first idea that naturally enters one's head is to utilize the drawing machinery; for by so doing we avoid the necessity of providing any special apparatus. For a long time there was a bias against this system; and when corves and kibbles were in general use, the privilege of being drawn up was granted only to the captains, foremen, and certain special workmen, such

as the *hookers-on* (*onsetters*, *fillers*) and the *shaftmen*, who had to look after the pumps.

The men stood either in the bottom or on the edge of the kibble, holding on by the chain with one hand, and guiding themselves with the other, so as to prevent the kibble from striking against the sides of the shaft. At St. Etienne, where small kibbles were used, the miner put one foot in the kibble or on its edge, grasped the rope or chain with one hand, and guided himself with the other foot and hand. When men were being raised or lowered in a kibble, care was taken that the other kibble should always be empty. Very often it was unhooked, and replaced by a counterpoise, consisting of a large block of wood fixed to the ends of the chains to prevent the hooks from catching in their course. A strong wooden or sheet-iron cover, or bonnet, was also fixed over the kibble to protect the men from the drippings of the shaft, if wet, and more especially from stones falling from the sides or from the surface.

Lastly, there was a recommendation, which it is true was rarely attended to, that the men should wear a safety-belt; *i.e.* a leather belt with a rope and hook, which was put into one of the links of the drawing chain. This precaution was adopted only when persons stood on the edge of the kibble, or were strangers to the mine.

The raising or lowering of men had to be carried on very slowly, at the rate of 3¼ feet (1 metre) per second at most, and the speed of the kibble was slackened, or all but stopped, when it approached the meeting-place, and was not again increased until the men signalled to the engine-man.

Particular care was required, when men were being lowered, so as to avoid a collision with the ascending kibble. As the two kibbles approached the men used to grasp the rope lightly, allowing it to run through their hands, and pushing it away from them so as to keep the two kibbles apart. This mode of ascending and descending was not in reality dangerous, although it required both coolness and care; it gave rise to very few accidents, and the risk of the rope breaking was small, as the weight of the men carried each turn was generally very much less than that of a kibble full of coal.

(**483**) There are many mines at the present day where all the men, and not merely a few special ones, are raised and lowered in this way. They go down in parties of six or eight. The very large kibbles can even take more than this, because some stand at the bottom and others on the edge. The most critical part of the proceeding is the getting into and out of the kibble; for the men are apt to hurry and push, and there ought to be some one to superintend the raising and lowering of the men in each shift.

In some mining districts, and it was formerly a common practice in England, the kibble is taken off altogether, and the men sit in loops formed by a small piece of chain with both ends hooked into the drawing chain. One or two men sit in each loop, and a regular *cluster* of men are lowered at once. The chain is stopped at several places at the surface and underground, so as to allow the different groups of men to get on and off. This plan, which probably appears very risky to persons unaccustomed to mining, is not in reality more dangerous than using kibbles, and does not appear to cause more accidents.

When men are *riding* either in the kibble or on the chain in the manner described, there should be some one at the surface or at the hooking-on place (*plat*) to receive them. The person told off for this duty seizes the rope with one hand and draws the kibble against the side, and with the other hand he steadies each man as he leaves the kibble until he is safely landed on firm ground. Provision, however, must be made for men who are *riding* at irregular hours, and do not find the banksmen (*landers*) or bottomers (*fillers*) at their posts. In this case the men have to *land themselves*, and for that purpose it is well to have a short piece of rope fixed up so that it can easily be caught hold of. By pulling this rope the men draw the kibble into a convenient position for getting out.

(**484**) Such then are the arrangements still in vogue in many places where men are raised and lowered by loose kibbles.

Where cages with guides are employed, each deck or floor of the cage can receive a party of men who go in and out with-

out danger; and, thanks to this system, men can be raised and lowered with all the safety and speed which the use of cages affords.

By this means *more men can be carried at one time. Less time is lost* in their getting in and out; the descent and ascent can be performed *much more rapidly* without any danger at the meeting-place; lastly, we are able to employ all the additional safeguards, such as catches and other contrivances attached to the cage, which we described in the last chapter.

These advantages are so great as to induce the winding machinery to be more and more used for raising and lowering men. Indeed, it may be said that, if the improvements in winding machinery have rendered great services to mining *directly*, by enabling us considerably to increase the daily output from deep mines, they have not been less useful *indirectly* by furnishing us with the means of raising and lowering the necessary complement of men for this larger output, without fatigue to them, and *without great loss of time to the engine.*

Some loss of time cannot be avoided; and, everything else being equal, its amount increases with the number of men and the depth of the shaft. It may happen, therefore, if a mine is shallow and the output very large, that it may fairly be considered more desirable to use ladders than to employ the winding machinery. The engine then remains perfectly free for drawing mineral, or for the accessory duty of sending down timber or other materials; and at the same time well arranged ladders kept well filled with men will deliver more men at the surface in a given time than the machine.

But if the depth is great enough to make it advisable to send the men up and down by the winding machinery, the question assumes different aspects according as we have to deal with loose kibbles or guided cages; *i.e.* with the old-fashioned pits, or those furnished with the latest improvements.

Let us take the case of a colliery 650 yards (600 metres) deep with a daily output of 500 tons.

If we assume that an output of this kind would require some 400 men in the mine during the principal shift, we shall probably

be taking a more favourable case than the average of collieries, at least on the Continent.

If loose kibbles were used, each holding ten men, it would be necessary to make 40 journeys to send down all the men.

Each journey would occupy—

	m.
Time lost between two consecutive journeys . .	2
Time required for a journey at a speed of 65 yards (60 metres) per minute	10
	12

Consequently it would take 8 *hours* to send down all the men, and just as long to bring them up, so that the mere raising and lowering of the men would occupy 16 *hours of the day*, which may of course be looked upon as quite out of the question.

With well arranged cages more than twice as many men can be let down at one time, so that twenty-five journeys will suffice instead of forty. Sixteen men at once are not too great a weight for the rope; for, taking each of them at 10 stone on an average, they will only weigh 1 ton, whereas the ordinary load is from 1½ to 2 tons (1600 to 2000 kilos).

We must reckon:

	m.	s.
Time lost between two trips	1	0
Journey at the rate of 20ft. (6 metres) a second, which is a lower speed than that at which ordinary winding can be carried on	1	37
	2	37

In round numbers we may say 3 minutes for each journey, or 1 hour 15 minutes for 25 journeys; that is to say, that the descent and ascent will only occupy two hours and a half instead of sixteen.

The conclusion to be drawn from the above comparison is very evident. When a mine is so deep as to render it impossible to use ladders, and when the daily output necessitates the employment of a large number of men, winding with loose kibbles is *utterly* inefficient, and it is absolutely necessary to adopt the most improved hoisting machinery. We must add that it is nevertheless advisable

to have ladders fixed in a special compartment of the shaft, as a means of escape in case of an accident,* or as a supplementary means of ascent if the machinery has to be stopped for repairs to itself or to parts of the shaft.

(485) The hindrance of ordinary winding for the 2½ hours above-mentioned, which we have assumed to be quite admissible, sometimes causes an inconvenient diminution of the output.

On the other hand, it is not always advisable or possible to put up machinery for this rapid winding.

It is not advisable in mines with a limited output, and where the mineral is obtained at several levels.

It is not possible when the winding has to be carried on in inclined (*underlay*) shafts, or shafts sunk perpendicularly as far as the deposit, and then continued along the dip.

All these different conditions are frequently met with in mineral veins, and are in some measure the regular state of things; and it is precisely these mines which, both theoretically and practically, are pursued to the greatest depths.

Thus metallic mines are at once those in which mechanical means are most needed for the descent, and at the same time those in which the winding machinery is least fitted, and occasionally utterly useless, for the purpose.

It is, therefore, quite natural that the metallic mines should have been the birthplace of the mechanical ladder called *man-engine* in England, and *Fahrkunst* in Germany.

The first apparatus of this kind was put up in the Hartz more than forty years ago, through the exertions of M. Albert, to whom we are also indebted for the introduction of wire-ropes. Some years later machines of the same kind were established in Cornwall, and since then their use has extended to other metal-mining districts, and even to some collieries.

The principle of the man-engine is very simple. Two parallel rods extending down the shaft are made to move up and down

* In the United Kingdom every coal or stratified ironstone mine must be provided with two shafts, each fitted with machinery for raising and lowering men.—*Translators.*

alternately *in opposite directions*, so that when one rod reaches the top of its course the other arrives at the bottom, and *vice versâ*. Little platforms or steps, just large enough for a man to stand on, are fixed at regular intervals on the rods, and above each step is a handle, which the man takes hold of to steady himself. When both rods have finished their stroke, the steps of one rod are exactly opposite those of the other, and so with the handles. A person who is being raised or lowered steps from one little platform to the other, lets go the handle he had been holding with one hand, and grasps that of the opposite rod with the other.

If he is on his way up he arrives with the platform of the rod which *has just made* its up-stroke, and he steps on to the platform of the opposite rod which *is just going to make* its up-stroke. The operation is exactly the reverse if he wishes to go down.

This contrivance corresponds to a ladder with movable staves, the miner having nothing to do but to shift himself slightly sideways in order to place himself on the stave which is *about to go up* or *down*, according as he wishes to ascend or descend.

Figures 380 and 381 represent the first machines used in the Hartz. One consisted of two wooden rods like pump-rods, whilst in the other each rod was replaced by two iron-wire ropes braced together by planks and handles. This latter man-engine was put down the Samson mine, at Andreasberg, which was then more than 400 fathoms (750 metres) deep, and the bottom of which is now more than 500 fathoms (900 metres) from the surface.

At first the man-engine was only used for going up; and there were occasional breaks in the series of steps, where the men had to climb a certain distance on ordinary ladders. The object of this was to prevent there being too great a load on the rods. There was also a ladder put up between the rods, even where there were fixed platforms, so as to provide a means of ascending if the machine happened to stop from any cause.

Figure 382 represents a man-engine somewhat similar to 380, save that there is only one rod and a series of fixed platforms. This kind of man-engine is used in Cornwall.

By the side of the rod there are a series of fixed platforms, or else niches cut in the side of the shaft. Each platform or *sollar*

is on a level with one of the steps on the rod at the beginning and end of the stroke. If a man supposed to be standing on one of the sollars wishes to ascend, he steps on to the movable platform as soon as the rod has completed its *down-stroke;* he is raised the length of the stroke, and then steps off on to the next sollar, and so on until he reaches the surface. If he wishes to descend, the operation is reversed.

(486) There are certain differences in the properties of the single-rod and double-rod man-engines which deserve a little attention.

If we suppose both machines to be worked by the same crank, with a radius R, *the number of revolutions per minute being the same in both cases,* the double-rod man-engine will take the men up and down at twice the speed attainable with the single-rod, because the men will be always in motion, and will pass through the space 4R, instead of stopping half the time and only moving the distance 2R. Thus a man will go down twice as fast with the double as with the single rod; but their capabilities as far as numbers carried is concerned are equal, because the number of men arriving at the end of their journey in a given time is equal to the number of revolutions made in that time.

Secondly, we must remark that it is by no means necessary that the speed should be the same in both cases, as we have supposed; in fact, the single-rod may be driven at a greater speed than the double one. This property of admitting of a greater speed does not depend on the mechanical construction of the man-engine, but is determined by the comparative facility afforded to the men for stepping from one platform to another. The ease with which one can step across depends upon the length of time the man-engine remains stationary; theoretically the stoppage is momentary, but practically there is a more or less marked pause when the crank is passing the dead-point. The stoppage may be measured by the time which elapses while two platforms, at first separated by a small given amount δ, become exactly level, and then separate to the same extent again. With the double-rod machine this difference of level δ takes place when each rod has only the distance $\frac{\delta}{2}$

to travel before the dead-point, or has travelled that amount after the dead-point; with the single-rod, however, it has to travel the whole distance δ. We know that the velocity of the longitudinal motion imparted to an infinitely long connecting rod by a crank is $R\omega \sin a$ (a being the angle of the crank m with its position at the dead point A, and ω the angular velocity, figure 382). The acceleration, therefore, is $R\omega \cos a \frac{da}{dt} = R\omega^2 \cos a$, and consequently the initial acceleration is $R\omega^2$. The distance x travelled by the rod in a very short time t, starting from the dead-point or just before it is reached, is given by the formula:

$$x = R\omega^2 \frac{t^2}{2}.$$

In the double man-engine, where both platforms move, the distance they become separated in the time t is $z = 2x = R\omega^2 t^2$; whilst with the single-rod machine the distance from the movable to the fixed platform will be (using accents to denote the quantities in this case)

$$z' = x' = R'\omega'^2 \frac{t^2}{2}.$$

There will be *equal facilities for stepping on and off* when $z = z'$ for $t = t'$, and consequently

$$R'\omega'^2 = 2R\omega^2.$$

If we make $\omega = \omega'$ then $R' = 2R$, and in this case we should have the same average speed, the same capabilities of sending down numbers, and the same facilities for stepping on and off.

If we suppose $R' = R$, we get $\omega' = \omega\sqrt{2}$, the average speed of travelling will be the same, there will be the same facilities of stepping off and on, and the capability of the *single rod* for sending down a number of men in a given time will be *greater* in the ratio of 1 to $\sqrt{2}$.

Besides, in either case, the increase of the length of stroke reduces the facilities for stepping on and off, diminishes the number of men who can be put on the rod at once, and lessens the load on it.

All these points must be taken into consideration in planning a man-engine. They may be summed up thus:

The average speed of travelling increases proportionally to $R\omega$.

The number of men that can be despatched in a given time increases proportionally to ω.

The facility for stepping off and on is inversely proportional to $\omega^2 R$.

The maximum load of the rod is inversely proportional to R.

We may remark, by the way, that the quantity $\omega^2 R$, the acceleration at the dead point, must be added to, or subtracted from, the weight of the men in calculating the load on the rod, according as it is acting from below upwards, or from above downwards.

If we come to figures, we see that with a speed of 8 revolutions a minute, for instance, the angular velocity per second ω, will be determined by the formula

$$\omega = 8 \times \frac{2\pi}{60} = 0^{m}\cdot 8381.$$

Therefore $\omega^2 = 0\cdot 70$, and if we take a crank with an ordinary radius, such as $0^{m}\cdot 90$ (3 ft.), we get $\omega^2 R = 0^{m}\cdot 63$, and consequently

$$\frac{\omega^2 R}{g} = 0\cdot 062.$$

Although this quantity is not so small as the analogous expression $\frac{e\omega^2}{2\pi g}$ determined in No. 454, it shows that the surcharges due to inertia may be neglected, and that we may calculate the dimensions of the parts as if they were in a state of rest. It would be a different matter if the angular velocity were greater, which would be unsuitable for the uses to which the machine is applied, or if the radius were very large.

(487) The length of the stroke of the double-rod engine must be equal to *half the distance between two consecutive platforms;* but in the case of the single-rod machine the stroke must be equal to *the whole distance between two consecutive platforms*, whether fixed or on the rod. With these arrangements it is evident that each man steps successively *on every platform* in going up or down. This

gives rise to a certain amount of difficulty when one set of men are going up and another set going down, as happens when the shifts are changing.* In order to avoid this the platforms have to be made roomy enough for men proceeding in opposite directions to pass each other at the dead-points; or, supposing the whole system of rods and platforms to be already in operation, we may *double the length of stroke.* In this case each man would only step on the odd series,

1 3 5 7 9

or on the even series,

2 4 6 8 10.

By making the men take the even series when going up, and the odd series in going down, or *vice versâ* the two sets of men pass in the middle of the stroke at the moment of maximum speed; but at the dead-points they always find the platform empty on the opposite rod.

If we wish to calculate the strain on the man-engine, it is evident that with the double-rod machine the men are always on one rod or the other; and with the single-rod machine they are either on a fixed platform or a movable one. In all cases the load on the engine, omitting the effect of inertia, is equal to the *weight of the men standing on the ascending rod minus the weight of those standing on the descending one.* If, therefore, at any time the men are all going down, the engine, instead of requiring power to drive it, may itself be driven, and need the application of the brake until all the men have descended. In such a case, where a man-engine is driven by steam, we can use Le Châtelier's system of the counter-pressure of steam with advantage.

(488) It might be supposed that although the double-rod may be inferior to the single-rod man-engine, as far as capability of sending down a given number of men in a given time is concerned, it has the advantage of its two halves balancing each other; and

* There is no difficulty of this kind with the Cornish or single-rod man-engine, provided that there are sollars on both sides of the rod; in that case the men who are going down always step on to the right-hand sollars, for instance, while those who are going up step on to the left-hand ones, or *vice versâ.*—*Translators.*

that consequently, leaving inertia out of the question, the load on the engine is merely the weight of the men going up minus the weight of those going down.

This advantage is more apparent than real. As man-engines are carried down to very great depths the weight of each rod itself would be a very heavy load on the point of suspension; and it is advisable to counterpoise it by balance-bobs, or special contrivances, which will be described in speaking of pumps. We will merely remark at present, that if the balance-bobs were simply placed at the surface they would relieve the rod of the man-engine where it is joined to the connecting-rod of the balance-bob, but not the parts of the rod underneath. It is, therefore, advisable to put up several balance-bobs at various depths, and counterpoise the whole weight of the rod in distinct pieces.

The strain at any point of the rods is equal to the total weight of that part of the rod hanging below the point in question, minus the effect of all the counterpoises attached to it. The balance-bobs may be so arranged, therefore, that the strain at any point chosen at random, as far as it is due to the rod itself, shall not exceed a given limit.

Where a rod is balanced in this way there can be no strain, theoretically, at any particular point save the weight of the men on the rod below this point.

This fact, which will crop up again in a slightly different form when we come to speak of pumps, constitutes an essential difference between a man-engine rod and a rope for winding. Every point in a rope has to support not only the load at the bottom, but also *the weight of the whole of the rope below the point in question.* A man-engine rod, on the contrary, has no separate load at the bottom, and if the counterpoises are well-arranged the strain at any given point should be due exclusively to a *load spread uniformly along the rod.* This load is the average weight of a man, say 140 lbs. (65 kilos.), distributed over the distance between two consecutive platforms, if there is only one set of men on the rod at once, or double that distance if there are men ascending and descending at the same time. (No. 487.) The weight of the rod has not to be taken into consideration.

We explained in paragraph 451 that in the case of tapering ropes the proportion between the section a at the bottom, and the section A in any point at a height H above it, is given by the exponential equation—

$$A = ae^{\frac{h}{\mu}}.$$

The like relation for a man-engine rod will be—

$$A = kh.$$

It is easy to deduce from this the fact that a longitudinal section through the axis of the rod will have its outline in the form of a parabola of the second degree, with a vertical axis, the apex being at the lower end of the rod. This results very plainly from the fact that the different horizontal sections A, A′, A″ . . . . which we assume to be similar, are proportional to the squares of their homologous sides; the outline is therefore such that the vertical co-ordinate is proportional to the square of the horizontal co-ordinate. We see clearly, from the above equations, without its being necessary to dwell upon this point, that the section of the upper end increases much more rapidly in the case of the rope than it does with a man-engine rod. It cannot be otherwise, because the latter is subjected to a load *distributed uniformly*, whereas with the former the *load increases from below upwards.* This result is expressed in figures 384A and 384B, which give exaggerated longitudinal sections of the rope and rod.

(489) It is worth while instituting a comparison between the relative capabilities of man-engines, and ordinary cages, for raising and lowering a certain number of men.

The two systems work in totally different ways. The cage takes a certain number of men to the bottom of the pit at its first journey; and the other men continue to arrive in little gangs at regular intervals during the whole time the machine is at work. With the man-engine, on the contrary, some little time must elapse before even the first man can reach the end of his journey, and then the others arrive one by one for each stroke of the engine, or in a nearly continuous stream.

Let us return to the data given in paragraph 484, where we found that with a perfectly well arranged winding machine it took 1 hour 15 minutes to bring up 400 men from a pit 650 yards deep.

We will assume for the sake of argument that a double-rod man-engine is worked by cranks of 3 feet radius making 8 revolutions a minute. This is a high speed, but one which is quite allowable. Each revolution of the crank-shaft corresponds to an ascent of $4 \times 3 = 12$ feet, and the men will be raised at the rate of $8 \times 12 = 96$ feet per minute.

The first man will take $\frac{650 \times 3}{96} = 20{\cdot}3$ minutes to ascend, and then 8 more will arrive per minute; *i.e.* $\frac{400}{8} = 50$ minutes for 400 men. The whole operation will take 1 hour 11 minutes in round numbers, or *almost exactly the same time as with the winding engine.* Thus *in the case under consideration* we may send down the men by the winding engine; or if it cannot be spared for this work, it is a matter of *indifference* whether we put up a special winding engine of the same kind, or an ordinary man-engine. We repeat that it is *a matter of indifference as far as time is concerned;* but, on the other hand, the cage requires a special perpendicular shaft, whereas the man-engine can work in any shaft, and even in a small compartment taken out of the drawing shaft.

If we were to assume other conditions the choice might no longer be a matter of indifference. To begin with, there are difficulties in using ropes for very great depths. Although it is theoretically possible by adopting tapering ropes (No. 451) to wind from these very great depths, still the ropes become very heavy, and overcharge the engines. In the second place, the length of time required for sending down a set of men does not vary with the depth and the number of men according to the same laws in both cases.

If we take the man-engine the time required includes a first term proportional to the depth H, and a second term proportional to the number of men N. It assumes the form

$$T = \alpha H + \beta N,$$

and, as we have just seen by the numerical example, we shall generally have $\alpha H < \beta N$.

In the case of the winding engine the principal term of the formula is proportional both to the depth and to the number of men. This term expresses the total time employed in winding; the other term is the length of stoppage between two journeys, and is proportional to the number of men.

We have therefore—

$$T' = \alpha' HN + \beta' N = (\alpha' H + \beta')N, \text{ with the relation } \alpha' H > \beta'.$$

We see that if N increases, both T and T' increase, but T' more rapidly than T. The same thing happens if H increases. In other words, the advantages of the man-engine become more and more marked as the *depth* and *number of persons* employed become greater. In fine, as far as we can judge at present, the man-engine appears to be the machine that will be largely adopted in the future.

To sum up, if for any of the reasons already given we are induced to substitute mechanical appliances for climbing ladders, we can first of all employ the exisiting drawing machinery; then, if the output is so great that it cannot be spared, a special winding engine must be put up, or else a man-engine. This latter machine is the only one that can be used in certain shafts, or where certain methods of drawing are practised, and its advantages become more and more apparent with every increase in the depth of the mine and in the number of persons employed.

(490) Such in our opinion is the conclusion we must arrive at with man-engines arranged in the manner described; that is to say, simple machines taking up little room, capable of being placed in a small compartment of a shaft and with steps made for taking one man at a time.

These man-engines are usually worked by water-wheels or rotary steam-engines. It is very easy to form an idea of the arrangement. The shaft of the water-wheel or steam-engine has a crank fixed to it, and by means of a long connecting-rod it sets in motion a single bob, the two ends of which carry rods connected with those of the man-engine.

Where this arrangement is adopted the size of the bob is limited by the dimensions of the pit, and consequently the stroke is too short and the rods are too far apart. It is better to have two bobs joined by a connecting-rod, one on each side of the shaft, and in this manner the length of stroke can be determined at pleasure. (Fig. 385.)

Instead of the two bobs we may adopt the more complicated arrangement of an hydraulic balance, which also permits the length of stroke being adjusted as thought desirable. The motor, whether steam or water, is made to work a piston in a cylinder full of water, the two extremities of which communicate freely with two twin vertical cylinders placed over the shaft. These cylinders are furnished with pistons, to which the man-engine rods are connected, and the whole arrangement works like the water-pressure engine described in No. 278, *Cours de Machines*, save that the varying speed is regulated by the motion of a crank instead of by valves. The length of stroke of the man-engine as compared with that of the force-pump is in the inverse ratio of the sections of the cylinders.

It should be borne in mind, that whatever plan may be adopted for working the rods, they are arranged exactly like pump-rods with regard to joints, guides, catches, changes of inclination, &c., all of which will be described later on. A man-engine rod differs in no respect from the main rod of pumps, save that it is usually smaller.

(491) Attempts have been made in two ways to increase the carrying capacity of man-engines. In the first place, the stroke has been lengthened, and the average speed increased, without causing any injurious shock at the end of the stroke; and secondly, the steps have been made large enough to receive several men at a time.

These alterations tend to shorten the time which must elapse before the first man reaches the bottom, and to diminish the delays between the successive arrivals of the rest of the men. In addition to this the intention was to give the men greater safety than was afforded by the narrow platforms of the original man-

engines. The large machines to which we refer are known as "Warocquères" in France and Belgium, and are so named after M. Warocqué, who erected the first in 1845, at the great Mariemont mines.

Figures 386 represent the arrangements adopted by the inventor. The "Warocquère" is worked by a double-acting steam-engine, with the cylinder placed directly above the shaft. The stroke of the piston is 9 feet 10 inches (3 metres), and the platforms on each rod are fixed 19 feet 8 inches (6 metres) apart. Each platform has two compartments—one for the men who are going up, the other for those who are going down. The two platforms take up very nearly the whole of the shaft, save a small space occupied by a fixed ladderway, in case the machine should accidentally be stopped.

The power is transmitted from the engine to the rods by means of a special contrivance known as the water-balance. It is composed of two twin cylinders, connected below and open above, each of which contains a tightly-packed piston. The space between the two pistons is filled with water, and the quantity is so arranged that when one piston is at the top of its stroke the other is at the bottom. Each piston-rod passes through a stuffing-box at the bottom of the cylinder, and is connected to one of the man-engine rods. The steam-cylinder is placed just above one of the twin cylinders. When the steam-piston goes up it raises the piston of the water-cylinder below it, and the other descends by its own weight. During the downstroke of the steam-piston the water-piston below it is forced down, and the other is consequently driven up.

The steam is distributed by valves, which are actuated by levers, and by two cataracts, which enable the length of the stoppage at the end of each up and down stroke to be regulated at pleasure. This stoppage is generally 2 seconds, and the number of strokes 12 to 14 per minute; say 24 seconds of rest and 36 seconds of motion to pass through a space of about 18½ fathoms (36 metres); consequently the mean speed of a journey is nearly 2 feet per second ($0^{m}\cdot60$).

A small force-pump is put to work, when necessary, to keep up

the supply between the two columns, and so prevent the length of stroke from being reduced by leakages; for otherwise the platforms would not meet exactly at the end of each stroke. A very simple brake may be put in for cases where too many men are being lowered at once. It consists of a throttle-valve fixed in the pipe which connects the two cylinders. This valve works like those described in the *Cours de Machines*, No. 274; and by closing it gradually it is easy to offer a constantly increasing resistance to the passage of the water, and so slacken the movement of the rods at pleasure.

(492) A modification of M. Warocqué's system, consists in replacing the double-acting cylinder by two single-acting ones placed in the position of the twin cylinders described above. The two pistons are balanced, and are made to work together by means of a chain passing over a pulley. Figure 387 is a diagram representing a machine of this kind erected at Seraing. In this case there are three pulleys, the object of which is to enable large pulleys to be used without keeping the rods too far apart. The figure also shows that bars of iron are used instead of the wooden rods of the Mariemont *Warocquère.* This modification no doubt contributes to the durability of the machine, but probably not to the smoothness of working. Of course it in no way affects the principle of the machine.

Another contrivance, which has been applied in several instances by M. Hanrez, consists in having two single-acting cylinders, as at Seraing, and making them work together by means of racks fixed on the rods, and a pinion. This arrangement, which is shown in figure 398, does not seem to present any special advantages. The racks and pinion must wear out very rapidly.

The machine is always under the control of an hydraulic brake, the piston of which, instead of being fixed to one of the rods, is worked by a connecting-rod, and a crank keyed on to the shaft of the pinion.

(493) The advantages claimed for the *Warocquère,* properly so-called, described in No. 491, and the similar apparatuses

worked by a cataract, are two in number. The first consists in the possibility of varying the number of strokes per minute, either by altering the length of stoppage between two strokes, or by altering the mean speed of the piston. The second is, that this system admits of a *greater average mean velocity* for a *given maximum velocity* than when the machine is driven by a crank. In our opinion these so-called advantages are in reality disadvantages.

We think that accidents might very likely result from the length of stoppage being altered. If the velocity of the piston varies too suddenly at the end of one stroke, or at the commencement of the next, it is not so easy to pass from one platform to another.

We consider that the motion produced by a crank and connecting rod, where the speed at the dead-points varies gradually and in a manner which the workman learns to feel as it were, is better than that of a *Warocquère;* because with this latter machine the motion may vary from day to day, or from one moment to another, on account of variations in the load, or the wishes of the engineman, besides which, the motion is as it were a series of sharp jerks repeated at badly-defined intervals.

This also appears to be the opinion of most English and German engineers, who hold to the man-engine, and who have erected, as far as we know, only one *Warocquère.*

Like them, we think it is very questionable whether the introduction of these machines has been a real step in advance for mining; for their mode of action is irregular, and they occupy a great deal of room in the shafts.

On the contrary, we are inclined to the opinion that a rotary machine is mechanically the best, on account of the kind of motion it imparts to the man-engine.

In fine, we consider that a man-engine intended for a great depth and for a large staff of men should be arranged as follows:

1. It should be driven by a rotary engine, distinct from the winding engine, but taking its steam from the same boilers. Men can then be taken up or down at any time without interfering with the winding.

2. It should have a single rod with a long stroke, 13 feet (4 metres), and should be driven at the rate of 8 double-strokes

per minute. The rod must be properly balanced at suitable intervals, and the counterpoises should be arranged so that each one shall *balance completely, firstly,* the length of rod between it and the next counterpoise below, and, *secondly, to a certain extent* the weight of the men who might be below it.

The excess of balance intended to meet the extra load should be very small along the greater part of the rod, and should be concentrated principally on the uppermost counterpoise; the object of this is to prevent any part of the rod from being subjected to a crushing strain when there is no extra load. The total of all the excess of counterpoise ought to be about one-half of the maximum load. The rod should be worked by means of the contrivance described in No. 490, with the sole difference that the pump forcing water under the piston should be single-acting.

3. The sollars and the steps should be 13 feet (4 metres) apart, and the sollars should be put up on both sides of the rod. There should be two handles on the rod above each step, so that as a man who is holding on with his right hand quits the steps, there is a handle ready to be grasped by the left hand of the man who takes his place. (This is the only way of making the ascending and descending streams cross without increasing the number of platforms immoderately, and without rendering the quantity ω^2R too great or the quantity ω too small.)

4. The strength of the rod must be calculated so that it can bear the greatest strain that can be put upon it at any point, which is the weight of a man multiplied by the total number of steps on the man-engine below this point.

5. The power of the engine required will be determined by the maximum number of men to be raised at once; it should be provided with a powerful fly-wheel in order to compensate for the fact that the weight of the men coming up acts as a resistance, and that of the men going down as additional power.

6. The steam-engine should further be provided with regulating contrivances, variable expansion gear, ball governor, &c. These are useful for cases of very variable resistances, which become *nil* at times, or even change into additional power, when all the men, or most of them, are going down. It might be advisable, with this

contingency in view, to have means of turning the steam against the engine.

7. Finally, the man-engine itself should be provided with all the necessary accessory contrivances, such as guides for preventing the rod from lashing, catches for preventing accidents in case of a breakage, and the various appliances for guarding workmen against blows in case of inattention.

We confine ourselves to this simple list of the various conditions which a machine of this kind ought to fulfil.

It is a matter in which men's lives are at stake, and consequently the engineer charged with the erection of a machine of this kind should carefully examine all the various arrangements intended to promote its safety. There is nothing absolutely obligatory in these arrangements, and the engineer is fully at liberty to introduce any modifications which may be thought desirable.

We will conclude by remarking that these machines are of great importance *for deep mines with a large staff of workmen*, and too great pains cannot be taken to put them up properly.

Suppose, for instance, an exceptional depth of 1,100 yards (1000 metres), the platforms 13 feet 2 inches (4 metres) apart, and the *extreme case where all the steps* are carrying men on their way up. The load to be lifted would be $250 \times 140 = 35{,}000$ lbs. ($250 \times 65 = 16{,}250$ kilog.), the space described per minute would be 8×13 feet 2 inches $= 105$ feet 4 inches ($8 \times 4 = 32$ metres), and the work per minute, $35{,}000 \times 105\frac{1}{3} = 3{,}676{,}671$ foot-pounds (per second, $\frac{16{,}250 \times 32}{60} = 8{,}660$ kilogrammetres), or a theoretical force of $\frac{3{,}676{,}671}{33{,}000} = 111$ HP $\left(\frac{8{,}160}{75} = 115\ \textit{chevaux-vapeur}\right)$.*

There would consequently be very great work and very great strains caused by the load being put on at the instant when the men pass from the fixed platforms on to the steps of the man-engine. For these exceptional depths it would evidently be necessary to take the men out in several successive gangs at stated times.

* In the example in English weights and measures the weight of a man is assumed to be 10 stone, or 140 lbs., which is 3·3 lbs. less than 65 kilos.; besides which the amount of work reckoned as a theoretical horse-power in England is slightly greater than the quantity adopted in France; for these two reasons we get a smaller horse-power in the English examples.

(494) It is quite plain from this last paragraph, and it was shown also in the case of winding treated in the preceding chapter, that operations which are simple and easy in mines of small or moderate depths are encompased with various difficulties and inconveniences as the depth increases.

The difficulties increase at a more rapid rate than the depth. The reason of this in the case of *winding engines* is that, in addition to the useful load, we have a *dead weight which increases rapidly* owing to the section of the rope becoming larger very quickly. In the case of the *man-engines* the *useful load* itself goes on increasing; and in both cases we cannot think of reducing the speed as the load increases, indeed we should rather have to increase it in order to maintain the efficiency of the machines.

For some time past, therefore, this question has been before the world: Are the means for raising and lowering men now at our disposal sufficient to satisfy all the requirements of the future, even if workings are to be carried on at very much greater depths than at present?

This question is important from a general point of view, and it is one that requires an immediate solution in some colliery districts, such as that of Charleroi, for instance, and in some metalliferous regions, such as the Hartz and Bohemia, where depths of 800, 900, and even 1,100 yards (800, 900, and 1,000 metres) have actually been already attained. It will not be long before the same question will have to be discussed for other localities; for, looking at the extraordinary development of human activity in every industry, it is not unreasonable to suppose that mines will be deepened *more rapidly than ever.*

As far as man-engines are concerned, our answer to the question is in the affirmative. We believe that these machines will be capable of raising men from any depths. We base our opinion on the fact, that any vertical rod, which is stationary or simply subjected to a reciprocating motion, may be *lengthened indefinitely*, without any risk of its breaking from its own weight, provided that it is balanced at intervals by properly arranged counterpoises. Such a rod might be of uniform section throughout, just as well as if it were lying horizontally.

A properly balanced man-engine rod suffers no strain due to its own weight; it merely feels the weight of the men standing on the steps. The number of these men fixes the amount of the strain, and, taking into account the average speed of ascent, determines also the power required of the engine. So long as we do not exceed a given number, an engine of given power will suffice, *theoretically*, however deep the workings may be carried. All we have to do as the depth increases is to *lengthen* the rod, and to *avoid exceeding* the fixed maximum number of men to be raised or lowered at one time.

(495) The conditions are no longer the same with a winding engine where a rope is wound on to, and unwound from, a drum, because the rope cannot be balanced by counterpoises attached to it directly. It is quite possible, as we have seen, to counterbalance the strain produced on the engine by the weight of the rope, but it is impossible to prevent the rope which is hanging in the pit from having to support, at any given point, not only the load at the bottom, but also all the weight of the rope below that point.

We have already seen (No. 450) how this consideration imposes a limit on the depths to which ropes of uniform section can be employed.

It is very evident that if a rope weighs P lbs. per yard, and if the greatest practicable load is Q', it will be *sufficiently loaded by its own weight*, and will be unable to carry anything more at its extremity, when H yards are hanging vertically, H being determined by the equation $Q' = PH$.

From the figures given in No. 448 we should find that this limit would be 820 yards (750 metres) for hempen ropes, 875 yards (800 metres) for ropes of aloe-fibre, 1100 yards (1000 metres) for iron wire ropes, 440 yards (400 metres) for chains, and 1640 yards (1500 metres) for steel wire ropes.

When tapering ropes are adopted there is no theoretical limit to the depth. The total weight of a tapering cable for a load R and depth H may be calculated by the formula $Q = R\left(e^{\frac{H}{\mu}} - 1\right)$, in which μ is a constant depending on the nature of the rope, and

equal to 1100 (1000 when depth is expressed in metres), for instance, in the case of iron wire ropes. (See No. 451.)

Supposing H = 1100 yards (1000 metres), and R = $3\frac{1}{2}$ tons (3600 kil.), as in No. 450, we obtain $Q = R\,(e - 1) = 6$ tons (6186 kil.). The mean weight would be 12·2 lbs. per yard (6 kil. per metre), that of the small end 7·1 lbs. (3·6 kil.), and that of the large end 19·3 lbs. per yard (9·8 kil. per metre).

These figures are not out of the way, as far as the rope itself is concerned, but the load on the engine would be very heavy.

Supposing H = 1650 yards (1500 metres), and the other data remaining the same, we should find

$$Q = R\,(e^{\frac{1}{2}} - 1) = 3\tfrac{1}{2}\,(4{\cdot}477 - 1) = 12\tfrac{1}{8} \text{ tons.}$$

The weight per yard at the small end being taken at 7·1 lbs., as before, the mean weight would be $\frac{12\frac{1}{8} \times 2240}{1650} = 16{\cdot}5$ lbs., and the weight at the large end $\frac{(3\frac{1}{2} + 12\frac{1}{8})\ (2240)}{1600} = 31{\cdot}9$ lbs.

If, on the other hand, instead of increasing the depth, we reduced it to 550 yards (500 metres), we should have—

Total weight of the rope, $Q = 2\frac{1}{4}$ tons;

Weight per yard at the small end, as before, 7·1 lbs. per yard;

Mean weight per yard, $\frac{2\frac{1}{4} \times 2240}{550} = 9{\cdot}1$ lbs.

Weight per yard at the large end, $\frac{(3\frac{1}{2} + 2\frac{1}{4})\ 2240}{1100} = 11{\cdot}7$ lbs.

The results obtained in these cases are summed up in the table below:

	H = 500 metres = 550 yds.	H = 1000 metres = 1100 yds.	H = 1500 metres = 1650 yds.
Total load at the small end . .	$3600^{k.}$...$3\frac{1}{2}$ tons	$3600^{k.}$...$3\frac{1}{2}$ tons	$3600^{k.}$...$3\frac{1}{2}$ tons
Weight per metre at the small end	$3^{k.}6$...7·1 lb. per yd.	$3^{k.}6$...7·1 lb. per yd.	$3^{k.}6$...7·1 lb. per yd.
Weight per metre at the large end	$5^{k.}9$...11·7 lb. per yd.	$9^{k}8$...19·3 lb. per yd.	$16^{k.}1$...31·9 lb. per yd.
Total weight of the rope . .	$2300^{k.}$...$2\frac{1}{4}$ tons	$6181^{k.}$...6 tons	$12500^{k.}$...$12\frac{1}{8}$ tons
Mean weight per metre . . .	$4^{k.}6$...9·1 lb. per yd.	$6^{k.}2$...12·2 lb. per yd.	$8^{k.}3$...16·5 lb. per yd.
Strain on the rope at the pulley at the moment of starting . . .	5900^{k}...$5\frac{3}{4}$ tons	$9786^{k.}$...$9\frac{1}{2}$ tons	$16100^{k.}$...$15\frac{3}{8}$ tons

A glance at this table shows that an increase in the depth is accompanied by the following consequences: Firstly, greater masses have to be set in motion; secondly, larger ropes must be used which are less easily wound upon the drums; thirdly, stronger pit-head frames and pulleys have to be erected; and lastly, the engines employed must be constructed more strongly.

Theoretically, therefore, it is not impossible to reach any depth if we adopt tapering ropes; but as the depth increases, all the parts have to be made specially strong; and if we wish to raise a useful load of a given weight, there is a very rapid increase in the masses that have to be set in motion.

If we are willing to accept this restriction, we must consider the question solved in the affirmative, and admit that *it is quite possible* to make the present methods of winding serve for very much greater depths. This is the conclusion we arrived at in the case of the man-engines, only the inconveniences increase much more rapidly with the depth in the case of winding machinery than they do with the man-engines.

Such, then, in our opinion, is the answer to the question put in the preceding paragraph; it is consequently unnecessary *at present*, and for some time to come, to seek for any new methods, and we need simply endeavour to improve upon existing machinery, without devising any system based upon totally new principles.

(496) However, we must say a word or two about a few attempts that have been made with this object in view.

The best-known machine, and indeed the only one which has ever been used practically, is that invented by M. Méhu, a clever mechanic, with much practical experience in mining. His first machine, the details of which had been very carefully thought out, was put up in a vertical shaft at the Anzin collieries; and subsequently two were erected at the Ronchamp mines, one in a vertical shaft, the other on an inclined plane starting from the bottom of a vertical shaft and following the line of dip. This latter machine was driven by an underground engine at the bottom of the pit.

M. Méhu's machine is figured in M. Ponson's work, to which we must refer the reader. It consists of a sort of man-engine or

Warocquère with two rods, one destined to lower the empty waggons (*tubs*), the other to raise the full ones; the waggons, after having been raised or lowered a given amount, are kept stationary by a sort of ratchet arrangement, whilst the rod makes its stroke in the opposite direction, and then carried on again on the return stroke.

Although the Anzin machine was working under the eyes of the inventor, it did not give satisfaction any more than the Ronchamp machines; and all were given up after having been tried for a few years.

There was much trouble from stoppages; at Ronchamp especially, where the waggons had to pass along two machines before arriving at the surface, the delays were very serious. After careful reflection the Ronchamp Company decided to put up with the inconvenience of a long stoppage of the works in order to take down the two machines; the one in the vertical shaft was replaced by an ordinary winding machine, whilst the dip workings were reached by deepening the vertical shaft and driving out a cross-cut.

The results of the experiments at Anzin and Ronchamp are decisive and quite sufficient to condemn M. Méhu's machine definitively. In our opinion a similar verdict should be passed upon all machines worked by reciprocating-rods, where the tubs are raised or lowered by a succession of short stages, because they necessarily require a number of more or less complicated catches; and each one must work with perfect certainty, for otherwise one stoppage would prevent all the other waggons from moving on. The hoisting would be stopped altogether, and there would be a great deal of trouble to set everything in order again. Besides this, these machines are placed in shafts where it is difficult to get at them for repairs; they are exposed to the action of water dripping on them, and to accidental falls of stones; they are liable to be dirtied by dust, and shifted out of plumb by subsidences due to the workings; consequently the various parts would require constant and careful looking after; and lastly, there is the liability to interruptions of working which are out of the question in a large mine.

In fine, if we suppose, for the sake of argument, that these machines were in use at the present day, it is very certain that

anyone who came and proposed to replace such a complicated system by a simple rope connecting the machine directly with the load, would be looked upon as rendering very signal service to the art of mining.

After this observation we need not describe the modification proposed by M. Guibal. His machine was like a *Warocquère* with two rods, as each waggon at the end of an up or down stroke ran across from its step to the opposite one in consequence of the rails on which it was standing being slightly tilted up. The movements of a man crossing from one step to another were thus imitated, and each rod served both for sending waggons up and down. There was a special arrangement for making the stoppage at each dead-point sufficiently long to allow the waggons to shift their position.

Guibal's machine has certain advantages over that of Méhu; the joints are less complicated, and even if it does get out of order you do not get such large accumulations of waggons. Besides this it is independent of any slight settlement of the ground around the shaft, because there is no necessity for making the steps of the machine coincide exactly with the fixed platforms. The mechanical arrangements of Guibal's machine are extremely ingenious.

In spite of all this it has never been tried in practice. Although it may be imagined that such a machine, with its constant stream of waggons, will deliver as much mineral as a good winding engine, or even more, we do not think it is likely to come into general use. We believe that for many years to come people will prefer the winding engine with the modifications described in No. 467.

(497) When the depth becomes such that the practical difficulties pointed out in No. 495 lead us to abandon the use of ropes, *although theoretically they could still be employed*, we do not believe that engineers will fall back on machines derived from man-engines in order to solve the difficulty.

The best solution of the problem is more likely to be found in the system invented by M. Cavé, a celebrated engineer. As long ago as the first *Exposition Universelle* in Paris, he exhibited a model

of this invention; but it passed almost unnoticed, although it was based upon a principle which seems likely to gain ground in the future.

This system, which is derived from the old atmospheric railways, and may be called the pneumatic system, consists in raising the load by compressing the air beneath, or exhausting the air above it. It is easy to imagine the entire pit, or one compartment, accurately walled up to a given template, with a sort of piston fitting it exactly. The load would either stand on the piston or be suspended from it. No packing would be required, for the piston, if made pretty thick, could have a series of grooves, in the usual way, which break the velocity of the sheet of air that tends to escape around it.

By means of a suitable ventilating machine a certain degree of vacuum is established above the piston or of compression below, whilst the opposite face is in free communication with the atmosphere. In this manner the weight of the piston and useful load are balanced as the piston goes up, whilst it is only necessary to balance the dead weight in the descent.

If d is the diameter of the pit in metres, P the useful load in kilogrammes, P′ the corresponding dead weight, P″ that of the piston, and H and H′ the heights of water in millimetres measuring the differences of pressure on both sides of the piston during the ascent and descent, ρ the weight of a cubic metre of water, we get the two equations—

$$\pi\frac{d^2}{4} \cdot \frac{H}{1{,}000} \cdot \rho = P + P' + P''$$

$$\pi\frac{d^2}{4} \cdot \frac{H'}{1{,}000} \cdot \rho = P' + P''$$

as $\rho = 1{,}000$ kilogrammes;

$$H = \frac{4}{\pi d^2}(P + P' + P'')$$

$$H' = \frac{4}{\pi d^2}(P' + P'');$$

from which we may deduce

$$H - H' = \frac{4}{\pi d^2} \cdot P.$$

Thus, for instance, in the case of the exhausting system, the machine must be arranged for reducing the pressure of the air in the pit above the piston to $10{,}330^{mm} - H$ and $10{,}330^{mm} - H'$ successively, and *vice versâ*, the air below the piston being in free communication with the atmosphere.

Let us take the case of a shaft 2 metres in diameter ($d = 2$ metres $= 6$ feet 6 inches), and suppose, as in No. 495, that $P = 1{,}600$ kilogrammes (1 ton 11 cwt.) $P' + P'' = 2{,}000$ kilogrammes (2 tons), we shall have

$$H = \frac{1}{\pi}\ (1{,}600 + 2{,}000) = \frac{3{,}600}{\pi} = 1{,}145 \text{ millimetres (45 inches)}$$

$$H' = \frac{1}{\pi}\ 2{,}000 = 636 \text{ millimetres (25 inches)}$$

$$H - H' = \frac{1}{\pi}\ 1{,}600 = 509 \text{ millimetres (20 inches).}$$

By applying the similar formula of No. 337 of the *Cours de Machines*, we may calculate the work expended theoretically in a pit of given depth to produce the ascent of the piston with its load and effect its descent empty; then fixing the length of time for the double journey we can calculate the horse-power required.

Suppose the pit to be 1,000 metres (547 fathoms) deep, and the speed of the piston 10 metres (32·8 feet) per second, the volume of air displaced per second will be $31^{cm}{\cdot}416$ (1,109½ cubic feet), and the theoretical work for the double journey is given by the equation—

$$\frac{\pi d^2}{4} \times 1{,}000\ (H - H') = 1{,}000P = 1{,}600{,}000.$$

If the work is done in 200 seconds, leaving out the time required for stoppages, the power required will be $\frac{1{,}600{,}000}{200 \times 75} = 107$ HP.

This is therefore theoretically the amount of power which would have to be exerted *continuously* by a machine acting between two large reservoirs—one at a pressure of $10{,}330 - H'$, which would furnish air during the descent; the other at the lower pressure $10{,}330 - H$, which would exhaust the air during the ascent. The machine ought to be employed to draw the expanded air out of this second reservoir and force it back into the first, and so make up for the loss from one and gain in the other.

The above calculation, however, is based upon a purely theoretical idea, which would scarcely be carried out in practice, because one does not see exactly how these large air-tight reservoirs are to be put up. In reality the exhausted air must be discharged into the atmosphere, and the power required during the ascent will be proportional, not to H − H′, but to H itself. Instead of a force of 107 HP acting *continuously*, a larger force, in the proportion of 1,145 to 509, will be required, and it will have to do its work in half the time; in fact, the power of the machine will have to be $\frac{3{,}600 \times 10}{75} = 480$ HP.

This is merely the theoretical work of the exhausting machine, such as would be calculated by taking a diagram from the pistons, but it would require an engine of a very much greater power theoretically to drive it.

Thus this system requires very large machines for two reasons: firstly, because they are only at work half the time; and secondly, because the dead weight is in no way balanced. No doubt the dead weight might be reduced by having two compartments connected, so that the piston in one should go up when that in the other went down; but this system would be very complicated, and it remains to be proved whether any advantage would be gained by it.

All we can do at present, therefore, is to point out the general features of the system. We may add that M. Blanchet is studying this method at the Epinac mines, and we may expect before long to learn the result of its application on a large scale.*

A smaller diameter has been adopted for the Epinac pit, 5 feet 3 inches ($1^{m}\cdot6$) instead of 6 feet 6 inches (2 metres); a much larger total load, 12 tons (12,000 kil.) instead of 3½ tons (3,600 kil.); and a smaller velocity, 22 feet (6 metres) instead of 32·8 feet (10 metres). The result is that the Epinac machine will have to be twice as powerful as the one alluded to above. The force required will be $\frac{12{,}000 \times 6}{75} = 960$ HP.

It is certain that there would be an advantage in reducing the load, and especially the dead weight.

* See *Annales des Mines*, 7me Série. Tome xiv. (1878) p. 266.—*Translators.*

However this may be, we cannot help regarding the pneumatic system as one which presents a question of great interest, not even yet thoroughly solved theoretically, and entirely new in its practical application.

(498) We must here remark that the volume of air displaced by the piston; viz., $31^{cm}\cdot416$ in the case we took for example, or 12 cubic metres (413 cubic feet) with M. Blanchet's dimensions, is the amount we can extract per second from the mine during the ascent of the piston; and by proper arrangements a similar quantity might be driven out of the mine during its descent. We have thus a means of ventilation which might suffice for small, inextensive mines with little firedamp.

Thus the pneumatic system may serve for ventilation *in addition* to its proper functions, and this may be of much importance as an auxiliary to the ordinary ventilating machinery, with which the mine should be provided in case of accidental stoppages of the hoisting apparatus. The ventilating power of the machine will be increased in proportion as we enlarge the diameter of the shaft, *augment* the speed, and *diminish* the load.

(499) We need not spend any more time in discussing this system, which seems likely to come into use. We merely wished to prove by calculations that it really is practicable. As to the future, our predictions, based upon our present experience, are as follows:

1. Ordinary man-engines are the machines destined to be employed for raising and lowering men in all very deep mines, because they can be extended to any depth, require only a small compartment, are suitable for shafts with varying inclination as well as for vertical ones, and possess a carrying capacity in some measure independent of the depth, and regulated only by the total number of men permitted to *ride* at one time.

2. Winding engines constructed with all the latest improvements seem as if they would suffice for all requirements for a long time yet. *Theoretically* their field of action is not limited by the depth, and *practically*, by using steel-wire ropes, we can wind from

very much greater depths than any hitherto reached. Of course, as the depth and output increase the machines will have to be made more powerful; the various parts will become more massive, and will be exposed to considerably increased strains, consequently it will be more difficult and troublesome to erect and work these engines. It will perhaps be found, when we reach much greater depths than those we now have to deal with, such as 550 to 600 fathoms and more (1,000 to 1,200 metres), that these inconveniences will become manifest in a very serious manner, and that we shall then feel a want of some other apparatus.

„ 3. Lastly, when this moment arrives, machines with reciprocating rods, like man-engines, will probably be found to present the same difficulties as those already met with in practice, and even to a greater extent, and the true solution of the problem will then be the adoption of pneumatic machines working on the principle of the old atmospheric railway, or rather on that of the pneumatic despatch tubes, used nowadays for sending messages.

CHAPTER XIX.

ON THE DRAINAGE OF MINES.

(500) In the preceding chapters we have described the various operations which are necessary in laying out and working a mine, from the time the soil is first broken to the moment when mineral is brought to the surface; and we have also explained the contrivances by which men are lowered down the shafts and raised again to the surface. We have thus made an end of all that concerns *the working proper*, but we have still to consider certain other operations which, without *contributing directly* to an increase of the output, are nevertheless indispensable in carrying on mining.

Among these is the *drainage*, in which we include everything relating to the means employed, not only for preventing the influx of water into the workings, but also for getting rid of that which always finds its way into them in greater or less quantity. The water met with underground penetrates into the workings in various ways. Sometimes it merely filters down through the pores in the rocks, which are frequently made up of fragments brought together mechanically; this is the case with alluvia, sand, more or less compact sandstone, and in general, all *purely sedimentary* rocks, which have not been subjected to contemporaneous or subsequent chemical or metamorphic action. Sometimes, on the contrary, the presence of water is due to fissures caused by contraction or shrinkage after deposition, or by elevations extending over the area under consideration, or lastly to subsidences and cracks produced by the workings themselves.

We shall divide this chapter into four sections. In the first we propose describing the conditions which tend to cause the infiltra-

tion of water into mines; and in the second we shall speak of the various processes which are employed to prevent this infiltration more or less completely. We shall then explain how mines are drained *naturally* by adit levels; and finally, in section 4, we shall treat the subject of *pumping;* that is to say, the mechanical means which miners adopt in order to get rid of the water, which they are unable to prevent from finding its way into the workings, when it is impossible for it to drain away naturally.

§ 1. On the manner in which water finds its way into mines.

(501) The quantity of water which *tends to infiltrate* into the workings of a given mine, and the quantity which really does find its way in, vary within very wide limits. Thus, in merely sinking shafts, there have been cases in which watery strata could not be pierced, because the shafts were too small to contain pumps enough to cope with the springs that were met with. (See No. 223.) At the other end of the scale we may cite the example of pits which were so dry while being sunk, that water had to be sent down for the men to bore with.

An examination of the contour of the ground and the nature of the rocks, and a hydrological study of the country, will generally enable one to form a rough estimate of the quantity of water likely to be met with in a given mine. However, we must recollect that the conclusions arrived at from such an examination are of a positive rather than a negative character. We mean that we shall generally meet with at least all the water *we have anticipated,* besides being not unfrequently troubled with it *quite unexpectedly.* This will be the case if we happen to strike upon some porous bed, which crops out in places where water can readily soak into it, or upon some large and more or less open fault. Either of these circumstances may let in water coming from a long distance, which a purely local survey, however well carried out, would not always lead one to suspect.

For information on the subject of underground sheets of water we may refer to what has been said about artesian wells. (Nos. 78

and 79.) Any circumstance that renders it probable that an overflowing spring, or water-bearing strata generally, will be met with, ought to make one expect to have difficulties in pumping while sinking a shaft.

For instance, let us imagine that Coal Measures existed under Paris (a highly improbable and almost certainly erroneous supposition). Very deep shafts would be required to reach the coal, several thousand yards deep; and the mere depth, which *per se* would resolve itself into a question of time and money, would not be the main difficulty. We should have to contend with the softness of the ground, and more particularly with an enormous influx of water. That very large quantities would be met with is very evident from the study of the geology of the Paris basin, and the various artesian wells both there and in the neighbourhood.

(502) Rocks of this description should be avoided as much as possible; but this cannot always be managed, and mining engineers have to make up their minds to sink through them when they extend over large areas; for instance, beyond the boundaries of a concession or "sett" which it is proposed to work. We gave instances of this kind in No. 224, and we described in chapter ix. the processes by which such shafts can be sunk, and this constitutes one of the most costly and difficult operations that the miner has to perform.

We must not forget that minerals lying under these water-bearing strata cannot be worked unless three conditions are fulfilled:

1. The lining of the shaft must be watertight for its entire length and at its base.

2. The position of the seams must be such that they can be properly isolated from the water-bearing strata.

3. They must still remain isolated from the water-bearing strata, even after the small subsidences caused by the workings have taken place.

It is, therefore, requisite that the beds under the watery strata should be comparatively impermeable, and so constituted that subsidences do not produce any clean fractures which remain open.

Beds of true clay will subside and stretch without breaking; beds of marl or shale may do so likewise, or else any cracks that form at first will gradually close up, either as the roof sinks down, or in consequence of their own plasticity under the pressure of the superincumbent strata. Beds of coarse-grained sandstone, or quartzose conglomerate, would not behave in the same way. Any cracks that were formed would remain open, just like those which have subsequently become mineral veins varying in width (No. 21), and water would run down through them freely from the beds above. Although it is by no means impossible that such a fissure should eventually be filled up by *débris* from the sides, or else be closed from the effects of a fresh subsidence, it is, on the other hand, more likely to be widened by the action of the water flowing through it.

We may safely say that it would be impossible to work some of the Mons collieries and all those of the Departments of the Nord and Pas-de-Calais if it were not for the beds of marl and clayey marl at the base of the Cretaceous rocks. These Cretaceous rocks are much cracked, and are full of water; but the marls are sufficiently thick, impermeable, and plastic, to prevent any influx of water into the Coal Measures.

In the same manner, if the new collieries of the part of Alsace-Lorraine taken from the former Department of the Moselle, continue to be worked, as no doubt they will be, they will owe their existence to the fact that the coarse water-bearing quartzose grits, met with for a depth of more than 150 yards, are succeeded by finer and finer sandstones, which even frequently assume a sort of clayey consistency, and so become somewhat plastic and impervious, though not so much so as the "dead measures" of Belgium and the North of France. The coarse grits belong to the *Grès des Vosges* or Bunter Sandstone, and the fine sandstones are either the basement beds of that formation or are of Permian age.

(503) When the influx is no longer due to subterranean water-sheets which have to be shut out from the shafts and workings, but is derived from faults (*cross-courses,* Cornwall) that have been cut into, the conditions are totally different.

Instead of having a sort of horizontal reservoir overhead ready to

discharge itself into the workings when dislocations of the strata take place, we have to deal with a more or less vertical trench which will not let out water unless the workings actually penetrate it or approach very close to it; but when this condition is fulfilled, water will escape from it, no matter at what depth it is intersected.

The quantity of water given out from a fault of this kind varies within very extreme limits.

If the fault extends for a considerable distance along the strike; if it has remained tolerably open, and has been but little filled up; if it crops out under the bed of a stream or somewhere else where water can easily find its way into it; if finally, as often happens, its throw is plainly marked at the surface, and it runs along the very bottom of the valley, then the influx of water may be sufficiently great to cause the mine to be abandoned altogether, unless it can be cut off by means which will be pointed out later on.

Sometimes, on the contrary, faults give off so little water as to make no appreciable difference in the pumping; but they are rarely quite dry. Indeed, proximity to a fault is generally heralded by increased humidity of the rocks, even when the fault does not let down any water directly from the surface. The reason of this is that a great fissure through the ground forms a sort of drain for any minor cracks which open into it on either side. It thus collects water and acts as a large receptacle which discharges its contents as soon as it is tapped by an opening of any kind.

The consequence of cutting a fault is to let in as much water at one point as would result from a sudden great extension of the workings. The same effect may be produced by any other imperfect junction between rocks, either parallelly to the stratification in sedimentary rocks, or along the plane of contact of two different formations.

This is almost self-evident, and it was the principal reason which induced us to place the *bed-veins* and *contact-veins* (No. 24) side by side with ordinary veins. We may therefore expect to find water in all places which are likely to receive deposits of the nature of lodes.

We are also liable to have influxes of this kind in rocks which are acted on by water, such as limestone.

The frequent occurrence of irregular cavities or caverns in these rocks is well known. These caverns are simply fissures in which streams of more or less acidulated water have circulated at some former time. Changes in the contour of the surface have diverted some of the streams, and their old beds are now left dry; others are still flowing, and a long list might be given of springs which are simply the points where such water-courses come to the surface. Of course, if a level happened to be driven so as to cut one of these underground streams, it is very easy to see that the workings might be suddenly inundated.

(504) These influxes resulting from water-sheets overhead being disturbed by the workings underneath, or from coming in contact with underground water-courses, are abnormal and exceptional, and the points where such water enters are in some sort *peculiar points* in the network formed by the galleries of a mine.

The usual state of things is that water finds its way in all over this network, oozing out from the thousands of little cracks in the walls of the galleries, without appearing anywhere in notable quantity. The walls are like a sort of filtering surface which nowhere delivers much water; but the total quantity given out is large on account of the great extent of this surface.

By reason of these fissures, ramifying in all directions, the rock resembles a spongy mass saturated with water. This water is stagnant, and its pressure at any point is that which would be given by the ordinary rules of hydrostatics before the workings in the mine commenced. It runs out in proportion as these workings are carried on, and continues to run because its place is constantly filled up by infiltrations from the surface.

Such then, in a general way, is the manner in which water finds its way into a mine. The influx is continuous, and consequently the drainage must likewise be carried on uninterruptedly.

It is evident that the surface of the sides of the excavations, or *surface of percolation*, increases indefinitely with the extent of the workings, that each orifice of escape delivers water coming from the surface, and that the hydrostatic pressure on this orifice must increase with the depth; consequently the quantity of water to be

pumped out per minute would appear to be proportional to the *total surface* of rock laid bare by the galleries, and, by Torricelli's theorem, to the *square root* of the distance of these galleries from the surface. It would follow from this, that if any *appreciable* quantity of water were met with in sinking a shaft, that fact alone would lead us to expect insurmountable quantities of water at a great depth, in consequence of the increase in pressure and the enormous extension of the surface of percolation. There is no difficulty in showing that this is a fallacy. We must allow *à priori* that there is a definite maximum for the quantity of water which can be extracted, quite independent of the area of the orifices in the surface of percolation, and of the hydrostatic pressure at these orifices. This maximum depends simply upon the absorptive power of the soil; because, to state the case briefly, the numerous little irregular channels which lead down from the surface through the ground to these little orifices cannot give out more water than they receive.

(505) This *à priori* reasoning is confirmed by an attentive examination of the question. If we suppose that no underground work is going on, and that we are dealing with the case of rocks impregnated with *stagnant water*, and not with the case of *underground streams*, it is quite true that the pressure existing at each point is that which may be calculated by applying the rules of hydrostatics. But if we now imagine that we all of a sudden make an excavation, like the workings of a mine, exposed to the atmospheric pressure, the water immediately runs in, and before long assumes a certain regularity of flow. Under circumstances of this kind the water finds great difficulty in moving along the little subterranean channels, on account of their ever-changing form, size, and direction, and the little streams from the surface to the orifices of escape are far from being continuous. The pressure is not, therefore, transmitted from one point to another, the channels cannot be considered as being filled everywhere, and within a certain zone around the workings it is the pressure of the atmosphere which tends to be set up in all the fissures through which water is circulating.

When once this state of affairs has commenced, the outflow *no longer bears any relation* to the hydrostatic pressure, but depends upon the greater or lesser porosity of the rock in this zone. It is therefore evident, that though the workings actually draw from the numberless cracks with which the rocks are traversed, the outflow increases but very *slowly* with the surface of rock laid bare, and may be regarded as *practically uninfluenced by the depth.*

We see also that workings which drain the rock at *a certain level* reduce the quantity of water which would percolate into workings at a *lower level* if these existed alone, because the first carry off part of the water which would otherwise find its way into the zone drained by the second.

Without dwelling any further on these details we will lay down the following propositions, in which theory is fully borne out by practice.

1. Putting aside accidental influxes, the quantity of water draining into a mine of given depth increases *with the extent* of the workings, but not in proportion to their extent; and the additional influx caused by a given extension of the workings decreases in proportion as the mine is more developed.

2. The influx of water into a mine, everything else being equal, does not tend to increase with the depth; on the contrary, the influx into a given extent of workings at a certain level will be less than it was into workings above that level.

3. *In any given state* of the workings the quantity does not increase with the lapse of time, but it may increase under modified circumstances, if subsidences produced by the mining operations are of such a nature as to be likely to let down water either from the surface or from superincumbent water-bearing strata.

As there is the possibility of letting water into the mine in this way, and at the same time for the purpose of preventing damage at the surface (such as disturbing buildings, drying up springs, &c.), it is advisable to carry on the mining operations so as to produce general subsidences and not great dislocations of the strata; or, at all events, if these dislocations cannot be avoided, efforts should be made to confine their effects to certain places determined beforehand.

§ 2 On the means of preventing the access of water into the workings.

(506) We see from what has just been said that the quantity of water finding its way into a mine may generally be considered as made up of two distinct parts.

We have, first of all, what may be called the normal influx, due to percolation of water from the surrounding rocks, and derived from the surface or from overlying and more or less watery strata; and, secondly, we have the accidental influx, due to supplementary percolations caused by fractures in the ground produced by subsidences, or from cutting great faults full of water, which may let in at certain points streams of greater or less importance.

Means may be taken, both at the surface and underground, to cut off entirely, or to a great extent, both these sources of supply, The precautions that can be adopted at the surface are simple; but they are necessarily incomplete, because they can only be applied at certain points of the concession (*sett*), whilst the percolation is going on, at all events during showers of rain, all over the surface.

Particular attention should be paid to points where the infiltration is likely to be continuous, such as the beds of streams, the bottoms of marshes or ponds, valleys with thick deposits of alluvium, which may remain saturated with water just under the surface, even when the streams have ceased to run in summer, or in the case of the so-called dry valleys which have no apparent stream at all.

The outcrops of seams of coal are also places where water may find an entrance, either on account of "old men's workings," or when a virgin seam is not entirely impermeable; lastly, water may find its way in parallelly to the bedding between the coal and the roof or floor. It is well known that in sinking through the Coal Measures, an increase in the moisture of the rock is a sign of approaching coal, unless it happens to be caused by a joint. It is also a matter of common experience to find the coal distinctly moist when the seam is cut in new ground, which has not been drained by lower workings or by the neighbouring valleys. Again,

when a level is driven in coal on the dip side of the workings, the *end* or *fore-breast* will generally be wetter than the workings a short distance behind it.

In order to prevent water from finding its way down from the outcrop, drains should be dug on the higher side so as to intercept the surface water, which is turned off beyond the outcrop, or carried across by a launder and emptied at a sufficient distance away. Pits formed by the "caving in" of old workings near the outcrop should either be filled up entirely and the surface properly sloped off and drained, or else they should be encircled by a trench to catch and carry off the water from the neighbourhood, and prevent any of it from gaining access save the rain which actually falls within the ring-drain itself. If it is likely that cracks will be produced reaching up to the bed of a stream, its course should be turned, and the bed made staunch artificially. This may be effected in various ways. Where the stream is narrow and occasionally dried up, you may remove the sand and gravel from the parts where cracks have been or are likely to be produced, as far down as the bed-rock; you then puddle this with a certain thickness of clay, and lay down the sand and gravel again so as to form a pretty regular bed.

In other cases a leat may be constructed in masonry for the stream to run in. This plan will not, of course, prevent cracks being formed by any subsequent dislocations of the ground, and there could be no question of putting in masonry here to *prevent these movements;* but any fissures that are produced are sharper, plainer, and more easily repaired in the masonry than in the rocks which support it. Instead of a leat lined with masonry, a wooden launder may be put down; this is, of course, less durable, but it is also less costly, and less liable to leak if there are subsidences of the surface. These various precautions do not entirely prevent infiltrations from the surface. However narrow a valley may be, the artificial bed only occupies a small part of it, and it cannot catch all the water that runs down both sides during times of rain. Practically the bed can only be made large enough to carry off the stream when low or at a medium height, and has not capacity enough when floods come down.

It is, therefore, generally observed, after a rainy season or after great floods, that the quantity of water to be pumped increases. Several weeks or even a month or more may elapse before this increase is felt, and it is temporary like the cause that produced it. Nevertheless, in erecting pumping machinery provision must be made for extracting, not the *average*, but the *maximum amount of water*, in order to prevent interruptions in the work underground.

Such, then, are the operations which have to be carried out at the surface; they are very simple and easily understood. Under certain conditions they may be very useful, if not even indispensable. There have been important instances of this kind in the Rive-de-Gier basin, where all the conditions likely to promote percolation from the surface seemed united. The coal seam is thick; it was formerly worked without filling-up; the basin is narrow, and it is traversed along its greatest length by a stream which is subject to great floods; and, further, there are outcrops on each side of the basin worked by the "old men," and furrowed by ravines, which in rainy weather send down torrential tributaries into the main river.

Great efforts have been made by the engineers of this district to contend with these difficulties, and they have been crowned with a certain amount of success. If it had not been so, it is doubtful whether the mines could have been kept at work.

(507) The works at the surface should be supplemented by arrangements underground for the purpose of *preventing*, as far as possible, *these dislocations*, whilst the surface works have to *combat their effects*.

These arrangements are not always combined in a manner to ensure success. It may even be said that the question is rarely thoroughly understood, and more than once it has happened that the measures adopted have had precisely the opposite tendency to what was proposed.

We therefore feel obliged to discuss, somewhat in detail, not only the circumstances which cause these movements of the ground, but also the conditions under which they are produced and propagated.

Theoretically, the movement produced in any kind of ground by an excavation *limited in all directions* is confined within a certain radius. We will suppose, for instance, an excavation to have a volume V, and the sides to be formed by rocks, which, after having been broken up and become settled, increase in volume in the proportion of 1 to $1+\delta$. The excavation V, and the hollow V′ formed by successive falls of roof will both be entirely filled up, and the falling in will cease, when we satisfy the equation

$$V'(1+\delta)=V'+V \qquad V'\delta=V.$$

Thus if the rock increases one-third in volume for instance, or if $\delta=\frac{1}{3}$, we get $V'=\frac{V}{\delta}=3V$, and $V'+V=4V$. In other words, the final bulk of the part crushed in will be equal to 4 times the space occupied by the original excavation.

But things do not take place exactly in this way in working a mine. Here there is generally one dimension which may be regarded as practically indefinite (No. 262), and indeed, as a rule, there are two when we are dealing with a bed or vein, and not a limited mass. The effects may then vary materially according to the circumstances. One of the first cases to consider is that of a thick bed overlain by rocks of moderate firmness, and worked near the surface by pillars without filling-up, and without letting the roof down. Such, for instance, is the case in the large gypsum quarries near Paris. As stated in No. 344, these quarries are worked by leaving solid pillars, and the normal result of this method is, or *should be,* not to cause any subsidence of the ground.

But if a great fall of roof happens to take place in one of the galleries, the overlying beds run in through the hole that is left; being of a loose nature, they spread out on the floor for a long way when softened by water, and on account of the large size of the chambers there is no check on the flow. The consequence is, there is ample room for fresh falls, and the "run" goes on until a conical funnel-shaped cavity is formed reaching to the surface. This is what is called a *fontis* in French. The apex of the cone is at the point where the roof broke originally, and the inclination of the generatrix is the greatest slope at which the beds will stand of themselves.

The result which follows in this well-known case is supposed by many engineers to be universal; and they make it apply to movements occurring over a large area as well as to movements originating from a single point, to deep as well as to shallow workings, to solid rocks as well as to strata of little coherency.

When they have to form an estimate of the effects produced by workings over a given area, they begin by projecting its boundaries on to the surface, and in this way they determine the area which would be affected if the subsidences took place *vertically* only; they then imagine a conical envelope outside the projecting cylinder, generated by a triangle, the apex of which describes the perimeter of the workings. The inclination of the generatrix to the axis is arbitrarily fixed at 45°, or any other angle which they think represents the natural slope of the rocks, and along which they consider the fracture should take place. There is no argument whatever to justify this doctrine. It is *purely arbitrary*, and it is not confirmed by practice. We may even go further, and say that it is not admissible theoretically; for if a conical mass were to slide down in the manner supposed, its bulk, which is relatively very great compared with the space to be filled up, would have to be reduced. It is very difficult to admit this reduction in bulk; indeed, we should rather suppose that there would be an increase from parts of the rock being broken up. The increase may be *nil* if the mass subsides in one block, as it were, without a number of cracks; but there never could be any diminution of volume.

The question is, therefore, in nowise solved by the summary process mentioned above, and it is necessary to go into the matter more closely.

(508) We will, first of all, take the case of a thin seam with a certain amount of dip, and worked by the filling-up system, such as we find in Belgium and the North of France.

Let A B (fig. 389) represent the section of a panel in which the coal has been removed and replaced by stowing. As a rule the stuff is not packed tight against the roof, and even if it were the pressure would be trifling compared with the load to be supported when the subsidence takes place. In reality the stowing does not

begin to act until it has been more or less compressed by the roof.

At *m*, in the middle of C D, the movement is greatest and the filling-up most compressed, and the subsidence spreads gradually to the right and left, until fractures take place at C and D, where the roof is kept up by parts of the seam which are still intact. After this fracture the layer forming the immediate roof of the seam rests on the stowing, and has separated from the second layer, which in its turn soon undergoes a similar process.

As these successive subsidences take place gradually, without the beds being broken up, there is no appreciable increase in bulk, and the different beds separate one after the other from their roof and settle down on their floor, the amount of subsidence being theoretically the same for each bed. We may suppose that this process is repeated gradually as often as we like, and we may therefore lay down the following proposition:

If the coal has been removed over a certain area, and the space filled up in a seam worked by the methods adopted in Belgium and Northern France, the subsidence of the roof on the filling-up causes fractures along the perimeter of the area at right angles to the plane of stratification, and the subsidence of the ground within the cylindrical space indicated by these fractures continues gradually without sensible diminution in amount quite up to the surface, whatever may be the depth of the mine.

It is evident, in the case of a horizontal seam, that the subsiding cylindrical mass stands vertically, and consequently the fracture appears at the surface as the vertical projection of the perimeter of the area worked away; but if the seam is dipping considerably the cylinder will be but slightly inclined, and its trace at the surface may not appear for some distance. This fact furnishes us with an explanation of the singular effect that is often noticed; viz., no damage at the surface directly above the workings, but, on the contrary, marked subsidences a long distance horizontally from these same workings.

What is true of a single seam may be applied in a similar way to the case of a series of parallel seams, or of one thick seam worked by slices with filling-up. The total subsidence in any given point

will be equal to the sum of the partial subsidences which the different seams or slices of the seam would have caused separately.

(509) Though this theory is perfectly justified by the facts when these are properly interpreted, there is at first sight an objection to it; but it is one which is easily answered.

Let A B (fig. 390) be a working area which causes the subsidence in question. It would seem natural that the fracture produced by the settlement of the ground should take place along the line of least resistance. The lines A *m* and B *n* at right angles to A B are longer than the lines A *m′* and B *n′* perpendicular to the surface; consequently it might be said that the fracture should occur in the direction of the latter.

This argument would be perfectly admissible, and perhaps the rocks would crack in this way, if the ground were perfectly homogeneous in all directions; but the actual result is quite different. The fracture is necessarily gradual, and extends from below upwards, each part subsiding in its turn where the parts below have given way.

In sedimentary rocks the plane of bedding is always a direction of easy separation, and, to be brief, the fracture at any time will always take place more readily along the perimeter A A′ B B′ than along the perimeter A C B, however small the distance A B may be compared with the thickness A A′ of the slice that falls at one time.

The rule laid down above forms a sort of theorem which ought to be uppermost in one's mind in endeavouring to estimate the effects likely to be produced at the surface by any given workings. This theorem may be applied with dips varying from nothing to an angle great enough to prevent the roof subsiding on the floor on account of friction. Beyond this limit we should have to take into account other conditions which we shall not discuss here; the subsidence would then tend to take place along the seam itself, and not at right angles to it. With the exception of this case, the proposition just enunciated enables us to follow the effects of the subsidences produced in a series of *parallel strata* overlying a given seam.

We must add a few words concerning the case where this parallelism does not exist throughout, either in a given geological formation or in passing from one formation to another. Suppose, for instance, to take a case which frequently occurs in practice, that Coal Measures are covered unconformably by stratified *dead measures* lying horizontally, and these in their turn by alluvium. Let A B (fig. 391) be the area which has been worked out and filled up. As far as A′ B′ the subsidence will go on according to the rule we have laid down.

The triangular prism A′ A″ B′ will sink down according to the same law, and even more easily than the rectangular prism A B B′ A′, because each bed will only be held on one side. When once the prism A′ A″ B′ has settled down, the movement will be propagated in the dead rocks along the vertical lines A″ A‴ and B′ B″, and its amount will be equal to the vertical projection of the subsidence felt by the points of the trapezoidal prism A A″ B′ B. Finally, on reaching A‴ B″ the movement will extend to the alluvium, which will sink into the cavity formed underneath it. The slope of the line of fracture will probably depend on the relation between the height of this cavity and the thickness of the alluvium. The last subsidence will be equal in amount to that of the prism A″ A‴ B″ B′, or rather a little less, because there will probably be a little increase in bulk of the alluvium during its subsidence.

Such then will be the result if the Coal Measures have a uniform dip.

If the dip *varies gradually* the straight lines A A′ B B′ will be replaced by normals at right angles to each bed traversed.

With *sharp variations* like those of the *rearers* of the Mons district, these lines, instead of being continuous, would present an elbow at the point where the sudden change of dip occurs. The angle of the elbow would be the supplement of that of the corresponding *hook*. (See figures 392 A and 392 B.)

(510) With the aid of these rules, and knowing the disposition and nature of all the beds in the Coal Measures, we can determine in a rational manner, and very approximately, at what points the

dislocations due to any given workings will manifest themselves at the surface.

It is *along the boundaries of the area,* determined in this manner, that there will be cracks and dislocations, properly so-called, liable to let down water into the workings, or to cause serious damage to property at the surface. *Within this area* there will merely be a general subsidence, but no dislocation.

This accounts for our seeing the ground cracked, and buildings tumbling down in one place, whilst close at hand there is nothing observable but a mere change of the level of the surface. The subsidence will be repeated for each bed that is worked, and finally, the surface may be plainly lowered to a very considerable extent without any marked rupture. Care must be taken in practice to confine the subsidences, and especially the dislocations at the edges of the subsiding area, to places where there is no danger of letting down surface-water. Therefore, pillars are left, or else the workings are purposely extended, so that the cracks produced on the borders of the working area, in the manner explained, may not reach up into dangerous places.

This theory is applicable, not only where it is desired to hinder the influx of water into a mine, but also when it is necessary to prevent damage at any special points of the surface which it is advisable to preserve intact. This is particularly requisite in the case of winding shafts, which should be disturbed as little as possible for fear of causing extra repairs, and preventing the machinery from working smoothly.

Very often all that is done for this purpose is to reserve a circular space around the shaft of a certain radius, say 40 to 100 yards, and not take away any mineral save for a few necessary drivages, all the true working places being outside this circle. This system may be *more than sufficient* in some cases, and *radically insufficient* or even *injurious* in others.

Take, for instance, the case of a pit O Z (fig. 393) intersecting two seams A B and C D at the points M and N, and suppose that the figure represents a vertical section of the pit at right angles to the strike. Let G Z′ and H Z″ be the traces on this vertical plane of the cylinder that has been reserved in the manner just explained.

From the points A′ M B′ and C′ N D′ erect perpendiculars to the dip, and from the point O draw O E F parallel to these lines.

A′ B′ and C′ D′ show the parts reserved according to the plan under consideration. It is easy to see from the figure that it is useless to reserve the parts A′ M and C′ N, and that the workings beyond the portions M B′ and N D′, left intact to the rise, will produce fractures at B″ and D″, and a first subsidence in the part O D″, and a second in the part O B″.

The portion which ought really to be left as a pillar is M F in the lower seam, and N E in the upper. It would be better not to leave any pillar at all than to reserve the parts M B′ and N B′, because in that case we should merely have to deal with a general subsidence of the whole of the ground, instead of having distinct fractures at B″ and D″.

Therefore, in any particular case, suppose the seam cut by a vertical plane along the line of dip and passing through the axis of the pit. All coal to the dip side of the pit may be removed without risk, whilst to the rise side we should leave a pillar *equal in length to the projection on the line of dip of the entire height of the shaft above its intersection with the seam.*

This proposition fixes the minimum amount of protection we should afford to the pit itself; but if, in addition, we wish to preserve the machines and buildings around it, we must extend this limit according to the requirements of the case. Suppose, for instance, that the buildings referred to reached as far as O′ on the surface, the pillar would have to be left intact as far as E′ and F′.

Such, then, is the method for determining the size and position of the protecting pillars along the dip; their boundaries along the strike are fixed by two planes at right angles to this line so arranged as to include the top of the pit and the buildings around it.

(511) Suppose, now, that instead of having seams worked with stowing, we come to the case where pillars are taken away and the spaces not filled up. Instead of simple subsidences without any increase in bulk, we shall find that, as soon as the pillars are taken away, the roof falls in, and there is an increase in bulk varying

in amount according to the manner in which the fall takes place. There is not that definiteness which there was in the previous instances, because these falls are necessarily irregular in character.

It seems to us that they will not be the same with a weak roof as with a solid one, nor with a very thick bed as with a medium one. The thicker the bed and the weaker the roof, the nearer we shall approach to the conditions described in No. 504; *i.e.* there will be a tendency to form a cavity widening upwards (fig. 394), which will become a regular *fontis*, to use the French expression, if it extends to the surface. But this will not be the case if the mine is deep enough, for then the cavity will become filled of itself, owing to the increase of bulk. As soon as this takes place, we come back to the preceding case, and the subsidence continues above the natural filling up in proportion to its compressibility. (See fig. 394.)

With very firm rocks the cavity will gradually become narrower upwards instead of wider, and the tendency will be to form a *bell-shaped* and not a *funnel-shaped* cavity. When once this *bell* becomes filled up, from the broken-up ground occupying more space than it did when in place, the subsidence will go on exactly as it does with seams worked with stowing.

There are thus two differences between thick and thin seams. *In the first place*, the fracture which is produced at the surface does not follow exactly the boundary of the area worked away; it changes according to circumstances, and may be at a variable distance within this line if the rocks are hard, or outside it if they are loose and soft. *Secondly*, the amount of subsidence which causes the fracture cannot be determined *à priori* from merely knowing the thickness of the seam; because it depends also on the manner in which the roof falls, and on the degree of compressibility of the fallen stuff which fills up the cavities. The subsidence may even be *nil*, or it may not occur for a very long time, and then it may be very slight. From this we may deduce the following paradoxical conclusion, which is nevertheless true, that in deep mines it may happen that working a thin seam of coal with stowing will produce as much subsidence at the surface as working a

thick seam by removing pillars and letting the roof fall in; indeed, in some instances, the subsidence will be even greater in the first case than in the second.

In all these cases we have taken it for granted that the workings were sufficiently deep to allow the breaking-up of the beds to be succeeded by subsidences before the action reached the surface or water-bearing strata.

If it were otherwise, the irregular dislocations producing cracks at the surface, or letting in water, would be manifest *all over* the area set in motion by the workings, instead of being *confined to the boundary.* If it were necessary to avoid such results in a case of this kind, a method of working by filling-up should be adopted, and the roof thereby prevented from falling in.

(512) We may sum up the principles which have been set forth in the preceding paragraphs (Nos. 508 to 511) as follows:—In seams *worked with stowing*, the only precautions necessary for preventing the percolation of water from the surface, or adjacent water-bearing strata, are to arrange so that the cracks, which are an inevitable consequence of the working, shall be formed in places determined beforehand; in seams *worked by pillars with fall of roof*, it will be necessary to stow in any exceptional places where the falls might lead to *irregular subsidences* at the surface or in the water-bearing strata.

We repeat once more, that the cracks, which may extend to any distance, occur at the boundary or near the boundary between the wrought and unwrought ground, and are at right angles to the bedding.

A pillar left in the middle of some workings for the purpose of protecting the bed of a stream, or some important building, is not always capable of fulfilling this object; it may even be injurious.

If it is too narrow it does neither good nor harm, because it is soon crushed and has no effect at all.

If it is wide enough (and the width ought to increase with the thickness of the seam), 30 or 40 yards for instance, it causes a series of fractures all around it at right angles to the seam, and

these fractures, therefore, will not be vertical unless *the seam is horizontal.*

When, on the contrary, the *bed is inclined* (fig. 396), a pillar A B left vertically below a brook may very possibly cause a fracture ending precisely in the bed of the brook. It is not therefore vertically below the stream that the pillar should be reserved. The first thing to do is to determine the plan of the pillar at the surface, and the outline should be projected, *not vertically* to A B, but *at right angles to the seam* at A″ B.″ It would be better to remove everything than to leave the pillar A B.

(513) Independently of the precautions just described for preventing water from entering a mine, measures must be taken to keep back that which has already found its way in naturally or through cracks, so as to hinder it from flowing into the workings now in progress.

For instance, a continuous pillar may be left between the present workings and "old men's workings" near the outcrop, or below old abandoned workings full of water, forming what is called in Cornwall a *house of water.* The presence of such underground reservoirs is a permanent danger for the mine, and they may be the cause of great disasters if they are approached too closely, either from want of due caution, or more frequently from their exact position being badly known, and their limits being irregular.

As a rule it is advisable to drain old workings of this kind by a drivage carried on purposely with all the precautions likely to prevent an accident. A narrow drivage is pushed on in the direction of the old workings, and one or two boreholes several yards deep are constantly kept in advance; oblique holes towards the sides or towards the roof or floor are also bored in some cases; for instance, where a thick seam is being mined, of which the "old men" only removed certain layers. (Fig. 397.)

In this manner the workings are always protected on all sides by a strong pillar, the thickness of which may be regulated according to the pressure of the water and the firmness of the rock. The pillar is shown in the figure by the dotted lines. The near approach to water is generally indicated by the boreholes beginning to be wet,

and then all arrangements are made so that the miners may retreat at the first alarm.

A wooden plug is kept ready to stop up the hole at once, or else the hole is bored through a firmly-fixed pipe which can be closed by a cock. The water can then be drawn off afterwards slowly if necessary, so as not to overpower the available pumping-machinery.

The operation of putting in these boreholes, which is easily described and understood, is necessarily somewhat critical when there is a heavy pressure of water, and it should consequently be entrusted only to prudent and careful workmen.

Tubbing, of which we have already spoken, serves a different purpose; it keeps the water out of the mine by stopping it back at points where it would otherwise flow in. We may repeat here that it is usually employed in pits which are sunk through water-bearing rocks; but it is easy to conceive that it might be used in a gallery which happened to cut a fault letting out a great deal of water, or some more or less aquiferous permeable stratum. (See No. 232.)

(514) Instead of putting in these water-tight linings inside shafts and galleries for the purpose of keeping back water which tends to spout out, it sometimes happens that we have to erect water-tight partitions to cut off water which is already running into the mine.

These partitions fulfil the same purpose as the isolating pillars of which we have spoken, and whether placed in shafts or levels they are called *dams*.

A dam may be made, for instance, in a tubbed shaft, which has ceased to be of any use, but still communicates with the rest of the workings. The dam should be put in below the tubbing to prevent an irruption of water in case the tubbing should fail anywhere from old age.

A dam is put in at right angles to the axis of a level at a point beyond which there is no necessity of penetrating, in order to cut off water coming from old workings, or from a spring gushing out into the level itself.

Dams are works of a special nature which demand great

attention from the engineer who has to put them in. They must be made as impermeable as possible, and firm enough to resist any pressure they are likely to have to bear; for great disasters might be caused by their giving way if large bodies of water were penned up behind them, and it must be borne in mind that the pressures they are subjected to are extremely great when the depth of water above the dam is considerable. Thus, for instance, a dam in an ordinary level 7 feet high by 5 feet wide will have to support a pressure of 731 tons if the column of water acting against it is 250 yards high. (Pressure of 875 metric tons on a dam 3·5 square metres in section under a pressure of 250 metres of water.)

(515) The mode of putting in dams varies according to circumstances, and depends especially on the firmness of the rock, the position and dimensions of the opening that has to be stopped, and the weight of water to be resisted.

If the ground is very firm, and does not seem likely to be affected by lapse of time, a sort of recess or groove 12 or 14 inches (30 to 35 centimetres) wide may be chipped out to receive balks of timber. These must be carefully worked up so as to fit together with the greatest nicety, and the joints between them must be caulked like those of two successive rings of tubbing; the outside of the dam must be made tight like the outside of a wedging crib. (Fig. 398.)

In dams of this kind, known as *straight dams*, the pieces of timber are arranged so that their extremities rest against the two firmest sides of the gallery, or, if the rock is equally firm on all sides, they should be arranged so as to have the least possible span. The rock must be dressed very carefully so as to leave as smooth a surface as possible. If the nature of the ground is such that a smooth surface cannot be obtained, as is the case with very coarse grits, the rock is dressed roughly, and then made smooth by a thin layer of cement. Where there is a parting of shale in firm ground which would easily break away, and in time allow the water to find its way round the dam, a stopping process must be resorted to. The shale must be cut out with the pick, and the groove so formed filled up tightly with hydraulic cement. Another plan is

to bore a hole in this parting rather bigger than its thickness just beyond the dam, fill it with hydraulic cement, and at once drive in a long wooden plug as far as possible.

By adopting either of these plans, it is clear that no water can find its way through, until it has fretted away the shale for a distance equal to the depth of the cement or wooden plug, which is impossible, or, at all events, cannot happen for a very long time.

If the ground, though firm, is not sufficiently strong to prevent all risk of the shoulder of rock cracking off under the enormous pressure which it supports, it is advisable to make the thrust come against the sides. This is effected by cutting the rock obliquely where the ends of the pieces come against it, forming as it were the abutments of an arch. The balks of timber are cut at the same angle and act like voussoirs. (Fig. 399.) In cases where the nature of the ground renders it necessary to lay the pieces horizontally, and where at the same time the level is very wide, each course may be made of two pieces, instead of one, forming two contiguous voussoirs. This is what is called a *lock dam.* (Fig. 400.) The two pieces of any row act like the two contiguous segments of tubbing.

Lastly, when the ground, though firm (an indispensable condition for any dam), does not afford any sufficiently solid or impermeable bed, or when the pressure of the water is exceptionally heavy, or the sectional area of the opening very great, it becomes necessary to replace the straight or lock dams by *spherical* ones.

The four sides of the level are carefully dressed for a length of about 6 feet 6 inches (2 metres) so as to form the faces of a pyramid, the apex of which would be some determinate point in front of the dam. (Figs. 401 and 406.) This point is also the centre of a sphere towards which converge the four faces of each piece composing the dam. The pieces of timber are cut into frustums of a pyramid 4 feet 3 inches to 5 feet ($1^m \cdot 3$ to $1^m \cdot 5$) long and placed lengthwise; they therefore act like the voussoirs of a spherical arch, the thickness of which may be proportioned to the pressure, no matter its amount, without requiring pieces of timber of abnormal dimensions.

Lastly, we may mention that the spherical arch may be con-

structed of masonry instead of timber. Masonry evidently affords the same advantage as timber cut lengthwise, of allowing a dam to be put in of any desired thickness; but it possesses the inconvenience, already pointed out in No. 231, when speaking of tubbing, of being liable to become cracked from movements in the ground, and of not being easily repaired after such fractures.

It is not, therefore, advisable to employ masonry for dams in levels where such movements may take place, although instances of this practice may be met with. It is better suited for shafts, because it is easy to stamp down on the top of the arch a good thickness of clay, which would not crack even if the masonry did, and would act like the *dead measures* in the Department of the Nord, which prevent the watery strata from discharging their contents into the underlying workings.

(516) To these general remarks on dams we will add a few details concerning the actual execution of the work.

In the first place, in order to make the dam as watertight as possible, it is advisable to do all the wedging and caulking from behind, *i.e.* on the side which will have to receive the pressure, so that this pressure may not have any tendency to open the joints. It may often happen, however, especially with a level, that there will be no means of getting to the back of a dam when once it is finished. In a case of this kind it becomes necessary to provide a means of exit for the workmen who have to work at the back of the dam as it approaches completion. Various arrangements are employed for this purpose.

In a straight dam, where the balks are acting like mere supports, a square opening is left by cutting away half the thickness of two contiguous pieces which are chosen large on purpose. The opening may be closed by a door hung on hinges and opening backwards, which must be carefully shut when the men have come through. The edge of the door is furnished with a lining of vulcanised india-rubber, which presses against a similar lining on the edge of the hole. The joint can be made tight by means of an arrangement like that employed for the cover of a manhole in a boiler, and later on the pressure of the water keeps it close.

With a straight or lock dam, in which the pieces act like voussoirs, the dam can be built up, all excepting the last piece, which is set up obliquely to its final position, so as to leave a passage for the workmen, and is then drawn into place by means of a screw. This method, which may have to be employed instead of the preceding one when balks of timber of sufficient size cannot be procured, is not very satisfactory, because the dam cannot be finally caulked on the outside.

Lastly, in the case of a spherical dam, the passage provided for the men consists of a conical cast iron pipe, with a flange at the larger end, which lies between four or six contiguous voussoirs of two or three rows; these are cut out in the form of a conical sector, fitting the tube exactly. When the dam is completed the tube is closed by means of a large wooden plug, set up on trestles behind the dam, the big end of which is provided with a ring of gutta-percha or vulcanized india-rubber, like the *gearing* of a pump bucket. It is pulled forcibly into the tube, and is driven in still further by the pressure of the water from behind. Sometimes the pipe is closed by a door, which is put up when required. This door is furnished with a cock, and thus affords an easy means of letting out the water if the dam has to be repaired, or taken out when it is no longer wanted.

It must not be forgotten that some provision has to be made for carrying off the water from behind the dam during the progress of the work, without causing any hindrance. For this purpose low dams are made in the level on each side of the final one, and they are connected by a wooden launder or piece of hose. In this way the water is carried from one to the other, and the intervening space left quite dry. The hose or launder can be shifted about as the work proceeds, and after all the pieces are put in, and whilst the final caulking is being effected, it can be carried through the hole which serves as a passage for the workmen.

Another precaution which is often thought advisable consists in arranging that there shall be no air behind the dam when the water begins to press against it. It is considered that air would pass more readily than water between the joints, and would so open a way for it. The air is got rid of entirely by boring a hole

through one of the pieces, and fixing a bent tin pipe at the back, which leads from the hole into a little cavity made in the rock. As soon as water is seen to issue from the hole, it is evident that no air is remaining in contact with the dam, and a long wooden plug is driven in with a mallet to stop it up.

Sometimes, and especially where it has rather a wide span, the dam is strengthened by other pieces of timber. As a rule a strong beam is put up against the middle of the dam, and then strutted against the roof and floor of the level. All the parts of this framework must be made to take their load very carefully; for if the thrust were made greater than the pressure of the water it would tend to push the dam back and so loosen the joints; this of course must be avoided.

Lastly, it seems to us that, in addition to the above precautions, it would be well to do something to make the joints remain watertight. In order to effect this object the back face of the dam should be covered with some impermeable coating, which should neither be liable to be affected by water, nor to crack if the pieces moved slightly on taking their load. A thick coat of tar covered with two sheets of tarred canvas would answer the purpose, or, still better, we could fasten on a sheet of vulcanized india-rubber; this is so flexible and elastic that the pressure of the water would make it adapt itself exactly to the face of the dam without cracking, no matter how much the pieces shifted on first receiving the pressure.

Figures 402 to 409, which are fully explained in the Appendix, show the different systems of dams, both for levels and shafts, which have just been described.

§ 3. On the drainage of mines by adit levels.

(517) The water that finds its way into a mine, in spite of all precautions at the surface or underground, must be got rid of somehow or other, and the drainage must keep pace with the influx, for otherwise the lower levels would be liable to be submerged, and the work temporarily suspended.

The mode of draining a mine varies according to the amount of

water flowing into it, and according to the position of the workings with regard to the contour of the surface. When the shape of the ground is such that all, or at all events part of the workings, are at a higher level than some point of the surface within a reasonable distance, we should naturally think of draining the mine by a gallery driven in from this point. This *adit* or *adit-level* (*sough, water-level, day-level*) must have just sufficient gradient to make the water run off, and it can be driven from the surface towards the workings or *vice versâ*, or simultaneously from both sides. When communication has been effected between the workings and the adit, all the workings above it can be drained naturally, and the water in the workings below need only be pumped up to the adit-level instead of being raised to the top of the shaft. The amount of pumping will be reduced, not only because a portion of the water will run off naturally, but also because the water pumped from the lower workings will not have to be lifted so high. This water will not be so great in quantity as it would have been without the adit level (see No. 505), because the water does not, as a rule, come from the bottom of the workings, but is caused by infiltrations from the surface; and the drainage produced in the rock by a large adit generally reduces the quantity of water in the fissures which convey it down into the mine.

It is easy to form an idea, if not of the *amount*, at all events of the *nature* of the effect produced on the drainage of a mine by driving up an adit-level into it.

Suppose, first of all, that the adit does not exist. The quantity of water to be extracted from the mine will *depend essentially* upon the degree of permeability of the surrounding rocks, as well as upon any other conditions more or less apt to favour infiltration from the surface; but it will, on the contrary, *depend very little* upon the depth, and, finally, it will increase with the extension of the workings, but at a slower ratio. (No. 505.)

Let V denote the quantity of water pumped from the mine per minute. We will now suppose that an adit-level is driven up which drains naturally all workings above it, and receives the water pumped from the deeper parts of the mine. The total amount of water delivered by the adit will be $V' > V$, because the

adit itself forms an extension of the draining surface, and thereby increases the inflow.

If, on the other hand, we designate by V″ the amount delivered into the adit from the workings both above and below it, we have the relation $V'' < V$, for the quantity of water received immediately by the adit cannot increase, and indeed of necessity diminishes, in a manner impossible to calculate, the amount that flows into the workings either above or below its own level.

We may sum this up by saying, that an adit level delivers more water than the pumps in the mine would have had to lift if the adit had not existed; but it diminishes the expense, mainly by reducing the height of the lift, and also, to a certain extent, the quantity of water that has to be raised by the pumps.

(518) Independently of these advantages, adits have another of a totally distinct nature; viz., that of affording an outlet, not only for the drainage of the mine, but also for water purposely collected at the surface, and introduced into the upper workings in order to create motive power. The amount of power is measured by the *quantity* of water at our disposal per second, and the *height* of the fall between the collecting-place at the surface and the point where it flows into the adit. Naturally enough the amount of power may be very considerable in a hilly country, if it is thought worth while going far enough for the point where the adit discharges itself.

The motive power created in this way may be employed not only for *winding* purposes above the adit, but also for *pumping and winding* from below it; and the extent to which such power can be utilised will increase with the depth of the adit from the surface.

These arguments afford a perfect explanation and ample justification of the immense works that have been executed in certain mining districts, and especially in Germany, for the purpose of ensuring the future of the deep workings. Thus, for instance, towards the end of the last century the George adit was driven in the Hartz. An interesting account of it may be read in Héron de Villefosse's *La Richesse Minérale*. Half a century later, in 1851, a

deeper adit was begun, called the Ernest Augustus adit. It is $10\frac{7}{16}$ miles (16,800 metres) long, exclusive of branches, and it was completed in fifteen years.

This adit is for the most part 5 feet 9 inches ($1^{m}\cdot75$) wide and 8 feet 6 inches ($2^{m}\cdot60$) high. Its gradient is 1 in 2,000 (half a millimetre per metre). In many parts of the metalliferous district which it drains it is 400 yards and more below the surface. This enormous fall can be utilised fractionally. Thus the upper part can be made to drive water-wheels, turbines, or rotary water-pressure engines, according to the height of fall required. The power can then be transmitted from these machines to winding apparatus, stamps, ventilators, in fact to all kinds of machinery employed at the surface. Then the rest of the fall will set in motion direct-acting water-pressure engines, which will discharge the water that drives them at the level of the adit, and will be used to work pumps below this level.

This great work leaves nothing to be desired with regard to the full utilization of the motive power of the water, and it is a remarkable monument of the foreseeing and persevering spirit with which mining operations have been carried on in the Hartz for more than three centuries.

But it is clear that this spirit would be applied improperly, in other words, the profit to be derived from the undertaking would be out of proportion to the cost, unless the district to be unwatered were of considerable extent both as regards area and depth. Besides this, the laws of the country must be such as to prevent individual owners from opposing insurmountable obstacles to the execution of a great work of this kind. This was the case in the Hartz, and unless all these various conditions had been united, it is probable that such works could not have been carried out, or, indeed, would never have been thought of.

(519) Take the case of England, on the other hand, where the spirit of initiative and enterprise, and individual energy, are certainly more highly developed than they are in Germany, and especially than *they were* when these great works were being executed. Although capital is more abundant, we only find a pale

reflection of the foresight and perseverance of the Germans, even in the most flourishing metalliferous districts where the output is larger than that of similar districts in Germany.

This remarkable difference is due to several causes.

In Germany, although the owners of a mineral property may be very numerous, the subdivision only affects the amount of profit to be paid to them; for the mines are worked solely by Government engineeers, who have the power to undertake works of general utility, such as the long adits we have referred to. In England, on the contrary, possession of the freehold generally carries with it the right to the mineral underground; consequently many of the mines belong to large landowners, and they are fully alive to the importance of their subterranean wealth, and know how to derive profit from it, either by working the mines themselves, or by leasing them to mining companies for a term of years.

We find that these companies work their properties with intelligence and zeal, and take the greatest pains to erect all their machinery on a very large scale, and yet they are unable to undertake works of such magnitude and requiring so much time as these great adits we meet with in Germany. The reason of this is, that, firstly, the separate *setts* or mining areas are too limited in extent, and bear no relation to the nature of the deposit; and, secondly, the leases are too short.

In this respect the German system is superior to the English.

Where the management of a whole district is centered in the same hands, the workings can be arranged for the general benefit, and undertakings of general interest can be carried on, which would be impossible if all the mines were separate, without any common bond of union, and their owners often jealous of one another. This centralization ensures the fact of the deposits being well and thoroughly worked; and, since a whole district can be treated as one concern, individual mines are enabled to tide over times of poverty which would have otherwise led to their being abandoned.

On the other hand, this centralization rarely furthers the introduction of improvements, as central authorities will usually be

contented with waiting before adopting them, until they have been tried in practice by others.

In short, it is by no means certain that mining districts under this regime, such as the Hartz, are in so satisfactory a condition, from a technical point of view, as if they had been divided up into a number of distinct mines without any common bond of interest.

Very probably they would not all be at work at the present day; for their past history shows that they have more than once been in a precarious position, giving small profits which would not always have contented mining companies, or losing money which would have necessitated more or less heavy calls on the shareholders.

Such, then, are the advantages of this system of centralization. It has, however, various disadvantages, which are inseparably connected with it. Although the managers may be enlightened, and not make any grave mistakes; although the projects for the future, after mature consideration, may be well planned, there will still be a lack in the execution of the daily work of that zeal and ardour which are never so energetically and constantly stimulated as by the personal interest of the agents. The managers as a rule are slow to increase the output; they do not initiate new improvements, and the necessity of doing everything according to a certain established routine, and of submitting all decisions to a long succession of directors one above the other, deprives them of all sense of responsibility, destroys initiative, and takes away from them that decision and rapidity of action which are indispensable in all commercial matters.

These advantages and disadvantages are in nowise specially connected with mining. They are invariably to be expected wherever a public body carries on any particular trade or manufacture instead of giving it up to private enterprise.

We may sum up the special case under consideration by saying that if the mines of the Hartz had been subdivided into distinct concessions and left to private enterprise, they never would have led to the execution of such works as the Ernest Augustus adit, nor would they have been worked without intermission, as they have been under the central administration which

has had their charge. On the other hand, as long as they could have been worked without loss (and it is not very certain that this has always been so), private enterprise would have considerably increased the output, and would have succeeded in extracting greater profits. At the same time the working classes would not have remained in the condition in which they existed until lately; viz., having a *right*, as it were, to their *daily work*, which was, however, often more nominal than real, and receiving provisions at reduced prices, or, in other words, insured of getting a living. As a set-off against these apparent advantages, on the other hand, they have been in a marked state of depression, and on a much lower intellectual level than that of mining countries governed by laws similar to those of England.

In a word, the German system affords all the advantages of centralization and general regulation; but with the English you obtain the much greater advantages, in our opinion, of better development of the mineral wealth and a raising of the intellectual level of the people, produced by the constant exercise of the spirit of initiative, and the energetic stimulus of private interests.

(**520**) Without dilating any further on these considerations, which carry us away from the main object we have in view, it is evident that adit-levels have very considerable advantages from a technical point of view, and that many mines *would not be worked at all*, or would very soon be stopped, if they could not have recourse to this means of diminishing the cost of pumping, and of procuring motive power. It is needless to add, therefore, that the driving of such adits is a matter which the managers of mines ought to take into serious consideration.

The first condition naturally is, that the contour of the surface should be suitable; in other words, the mines must be situated in a district hilly enough to allow of the mouth of the adit being found within a reasonable distance, and at a sufficient depth below either part of the underground workings, or places where reservoirs of water can be formed.

It will be necessary, firstly, to consider the extent of workings that can be drained naturally by the adit, as well as the amount of

work likely to be done below it; secondly, to estimate the cost of pumping from these lower workings; thirdly, to calculate the amount of hydraulic power that the adit-level will place at the disposal of the mine, not only for pumping, but also for other purposes; lastly, to compare the relative expense of the hydraulic power with that of steam, taking into consideration the cost of erecting the machinery in both cases, and the cost of coal in the second, &c. &c.

This general examination, which has to deal with data of a necessarily uncertain nature, such as the presumed extent of the workings below the adit, and the quantity of water likely to be met with there, cannot, of course, lead to any precise result; it is evidently not a question of figures with a definite numerical answer. This, however, is an additional reason why we should study the question with all possible care, why we should look at it attentively on all sides, and ponder over each part of it. Finally, after having taken due account of all costs, both of plant and of working, as well as of interest upon the expenditure for a certain term of years, for instance until the expiration of the lease, we should decide upon adopting the plan which is the least expensive.

It cannot be said that the question has been thoroughly studied until all these points have been duly examined.

(521) If the result of this thorough study is that an adit should be driven, no time should be lost in beginning it, and the work should be pushed on with all possible vigour, for the same reason as that which applies still more forcibly to a large tunnel; *i.e.* that the work does not begin to be profitable *until it is finally completed*, and that consequently the dead loss of interest on the capital locked up increases with the time required for finishing the drivage.

Every means should therefore be taken to hasten the completion of the work as far as the money at one's disposal every year will admit. The driving should be begun at both ends, if possible, and, indeed, also at intermediate points, the precise position of which must be determined by a very careful survey. At the present day the errors of such a survey are measured by a few inches only, and

consequently the headings may be pushed out from the intermediate points without any fear of their not meeting accurately with those that are driven towards them.

Points for commencing these intermediate drivages may be obtained by sinking special shafts from the surface or by galleries starting from existing workings. The distances between these points must vary according to the special circumstances of each case. If the shafts need not be deep, or the cross-cuts long, the number of such intermediate points may be increased. Besides, when once the total number of shafts has been fixed upon, it will be well to sink them most closely together where they have to be deepest, in order to make all the drivages communicate with each other about the same time, because none of them can be of any use until the adit is quite complete all the way through.

In order to decide upon the total number of shafts to be sunk, it will be necessary to ascertain whether or no the advantage gained by speedier execution of the adit by having the shafts close together will make up for the extra expense; in making the comparison, all circumstances must be taken into account, particularly the interest to be paid on the capital expended on the work, and the annual saving on the cost of pumping which will be effected as soon as the drivage is completed.

In the case of a long adit it will generally be found advisable to employ boring machines (Nos. 158 *et seq.*), if not in all the *ends*, at all events in all such as are likely to be driven a long way from a shaft, in consequence of special circumstances, such as great depth of the adit below the surface, which would render a multiplicity of shafts very expensive. The question of the distances between the shafts should be studied under the two aspects of hand labour and machine work. We should compare the extra expense of *first cost* and *price per yard* of the latter system with the divers advantages resulting from greatly increased speed. It will then often be recognised that in a work likely to be of long duration, a saving of time is of so much absolute value that we have to give the preference to boring machinery even though the cost may be greater.

We lay some stress upon these points in order to prove that the problem of driving an adit level in the best possible way, is not

always so easy as it appears at first sight from the simplicity of the object in view.

The question is very easily understood in a general way; but it becomes very complicated if we wish to look at it from all its aspects, and if we are desirous of feeling certain that the solution we arrive at shall be the best in all respects, not only economically and financially, but also from a technical point of view.

(522) When once a decision has been come to, the mere execution of the work does not involve any new process. We have simply to apply the different methods described in the preceding chapters.

Adits are usually driven of about the same width as *cross-cuts* (*stone drifts*), say 6ft. to 6in. ($1^{m}\cdot80$ to $2^{m\cdot}$), and should be high enough to allow boards being fixed to form an easy travelling road above the water, say 8 to 10 feet ($2^{m}\cdot50$ to $3^{m\cdot}$).

Even if the adit is not intended for the ordinary conveyance of mineral, it may be desirable to put in a tram-road, and the necessary crossings, for facilitating the work during its progress, bringing in materials, and for repairs.

Where large quantities of mineral have to be carried through an adit, its width may be increased, and a double road put in all the way; but, as a rule, a first-class adit level does not serve for the conveyance of mineral, at all events to its mouth, because the outlet is usually too far away from the mines.

The longitudinal section of the adit should be laid down with care, so as to lose as little level as possible on the entire length. As has been shown in No. 149 of the *Cours de Machines*, the gradient may be much less than 1 in 1,000. Indeed, the instructions often given to the men in such cases are to drive the gallery at a *dead level*, marks to guide them being put up at the proper level in each air shaft. As the distances between these shafts are not usually very great, there is not the slightest difficulty in making two opposite drivages communicate exactly; if, however, the intervals were great, it would be necessary to put in other marks in different parts of the drivages.

Precautions should be taken to ensure the impermeability of the

water-channel formed by the bottom of the adit; and for the same reason as that explained in the case of a stream running at the surface. If there were fissures in the bottom of the adit, some of the water constantly running over them would be let down through them, and would then have to be raised by the pumps, lifting the water from below the adit level.

We took it for granted that the bottom of the adit was thoroughly watertight when we stated, in No. 518, that the ordinary effect of an adit level must be *to reduce the quantity of water to be raised by the pumps.*

This would no longer be the case if the adit were not watertight; but, on the contrary, the quantity of water to be pumped up might increase to almost any extent, because the same water might be lifted up over and over again.

To prevent a leakage of this kind adits that are driven along the course of a deposit should be carried into the footwall rather than the hanging-wall side, and at least part of the bottom of the adit should be in the footwall; that is to say, in a place which is not liable to be shaken by the workings. Where the adit is a cross-cut, preference should be given to the footwall side if the drivage can be carried in from either direction; but should it be necessary to drive through on the hanging-wall side, the adit should be made secure by a safety pillar laid out in accordance with the theory explained in Nos. 508 *et seq.* In other words, the axis of the pillar ought to coincide with that of the adit, not in horizontal projection, but in orthogonal projection on the plane of the deposit.

In places where an adit is liable to be disturbed by workings, it may be lined entirely with masonry with piers and an invert, even when these are not necessary for supporting the ground, and any cracks which appear in this masonry should be stopped up at once.

In crossing a deposit which has been worked close by at a lower level the water should be carried along a wooden launder, which should be suspended in such a manner as to be affected as little as possible by any dislocations in the neighbourhood.

(523) We will conclude these general observations on adit levels by remarking that this system of drainage is much more used in

working mineral veins than in collieries. Save a few navigable levels, which have been driven for *the conveyance of mineral* and not for *drainage purposes*, we can only cite a few unimportant adits in colliery districts, even where the surface is hilly; and these have been driven up from the bottom of a valley along the strike for the purpose of preventing, as much as possible, the surface water from soaking down into the actual workings below the level of the valley. A work of this kind has nothing in common with the great district adits referred to excepting the mere name.

There are many reasons why these great adits should be principally employed in vein mining.

In the first place mineral veins are usually situated in more hilly districts than coal seams, and consequently the shape of the ground is more favourable for laying them out. Secondly, metalliferous mines are usually *much more burdened with water* for a given extent of workings than colleries. Thus, for instance, there is no comparison between the quantity of water raised from a large colliery in Northumberland, and that pumped out of a large metalliferous mine in the same county or in Cornwall. In the former case the workings are under a great thickness of regularly stratified Coal Measures, consisting mainly of beds of shale but little permeable to water; here it may not even be necessary to have a special pumping-engine. In the metal mine, on the contrary, though the extent of workings may be less, a pumping-engine of several hundred horse-power is frequently indispensable.

The difference between the two cases is explained very naturally. A long and more or less permeable outcrop renders the infiltration of water into a lode very easy; and the contents of the vein are often themselves evidence of the ease with which water could penetrate into it in days gone by. There is nothing unnatural in supposing that this facility of entry has not entirely disappeared.

Thirdly and lastly, metal mines cannot so readily employ steam pumping machinery as collieries, because fuel is always much dearer, and is sometimes very scarce. Besides, many of the metal mines have been worked from very remote times, and many of them possess deep adits which were driven before steam-power was known.

These reasons fully explain why it is that we must go to metalliferous districts if we wish to find examples of the greatest works carried on for draining mines; whilst we must turn to collieries, where the possible output from one shaft is such an essential factor, if we desire to see the winding machinery on the largest scale.

§ 4. On draining mines by mechanical appliances.

(524) In spite of all precautions at the surface or underground, it is impossible to prevent some water from finding its way into the workings. Even where it has been possible to drive an adit level only part of the water is drained away, and some soaks down into the workings below.

We must now discuss the means of drawing off the water from such mines or portions of mines as are not drained naturally. We may distinguish temporary appliances for draining a small portion of a mine, and permanent machinery for lifting the water from the whole of the workings.

In principle the workings should be so arranged that all the water should flow naturally to the pumping-shaft, either into the *sump* or *fork*, or into the cistern of one of the series of pumps in the shaft. As the gradient of the galleries is chosen with a view to facilitate the tramming, there is no difficulty about a ready flow, and a mere gutter, if kept clean, leaves the rest of the bottom of the level dry, and carries off all the water that drains into it. However, this principle is not rigorously adhered to in every case; as it may be advisable, and occasionally even necessary, to depart from it. Thus, for instance, if drivages are being pushed out from a shaft to meet the galleries driven from neighbouring pits, one must be uphill and the other downhill if a uniform gradient has to be preserved throughout the entire level.

Other cases may present themselves. For example, a heading for bringing in air in a badly-ventilated part of a mine troubled with fire-damp will be much more easily driven downwards than upwards. The situation of a part of the deposit may also induce one to work it in a manner requiring artificial drainage. By way of illustration,

a district lying between two faults may be below the level at which the gate-road should be maintained. Again, a gallery driven up the rise of a seam, on meeting successively with saddles and troughs, will come to places beyond which the seam may dip down away from it. It may happen that a *hook* (No. 17) descends a little below the level of a crosscut by which the corresponding *flat* and *rearer* are worked, and leaves too small a quantity of mineral to make it worth while driving a special crosscut. It may also be necessary to sink below a level, either for the purpose of exploring the ground or of hastening communication between two shafts.

(525) In these different special cases, which we need not enumerate fully, temporary appliances are used with which it is well to be acquainted.

Where there is a long drivage with a small gradient downhill, such as an intermediate piece of level from an air shaft, the water may be got rid of simply by baling. For this purpose little pits, or *sinks*, are cut out at intervals in the floor of the gallery, and launders are fixed sloping in a contrary direction to that of the drivage. The water is then baled with a bucket from the sink into the launder above it, and it runs into the next sink, and this process is repeated until it at last reaches a point from whence it can run into the shaft.

If the place to be drained is separated from the rest of the workings by a mere barrier beyond which a point can be found at a lower level, a siphon may be introduced to draw off the water. It will only act so long as the top of the barrier is not more than 20 to 23 feet (6 or 7 metres) above the surface of the water. The siphon should be filled by means of a tube at the top, and the two ends should be provided with valves worked by floats so arranged as to close the orifices before the level of the water sinks below them. By means of this simple contrivance the siphon always remains charged.

Water may be got rid of from descending workings by carrying it in a tub on two poles, like a hand-barrow, or else putting the tub or bucket on to a trolley running on a tramroad.

Lastly, hand-pumps may be used with the suction-pipe dipping

into a little sink, and the delivery-tube carried up to a point where the water can be discharged. These pumps can be constructed of wood in a very simple manner, and all the various parts are made by the mine carpenters. They consist of the trunk of a fir-tree, with a comparatively small hole bored for the suction-pipe, and a larger one for the working barrel and delivery tube. Where the two holes meet there is a shoulder which receives the stationary valve. The piston or bucket is hollow, and carries a valve; it is raised and lowered by means of a series of iron rods with a cross handle.

The stationary valve or clack consists of a seat, which is a hollow cylinder of wood, with a circular piece of leather nailed on to it by a tail-piece or *heel* which forms a hinge. The leather is stiffened by being held between two round pieces of wood, the upper one rather larger, the lower one somewhat smaller than the hole through the seat. The seat is made to fit closely into the working barrel; it is packed with greased hemp, and then pushed into its place with the aid of an iron loop which is fixed to it. This serves also for drawing it out when the packing has to be renewed or the clack changed.

The bucket is shaped like the clack seat, save that it is rather narrower at the bottom in order to receive a band of leather or vulcanized india-rubber, which is opened out and pressed against the sides of the working barrel by the weight of the water acting on it during the up stroke.

The general arrangement and the details of these pumps are shown in figures 410. They are not made more than 26 to 33 feet (8 to 10 metres) long, and can be easily moved about and fixed in their place. Inclined galleries can be drained by laying these pumps on the ground, and a series of them can be employed where such a drivage is very long.

At the present day metal pumps are usually adopted instead of wooden ones, and are worked more or less after the fashion of fire-engines. They are generally preferable to the wooden pumps, because they can lift the water in one jet without any repetitions, and because, as a rule, they are so arranged as to be more favourable for getting the best effect from manual labour. There are many varieties of these pumps; and the different makers often have

a speciality for one kind of construction or another. We do not propose to describe them, for this would necessitate our entering into a quantity of technical details without special interest for mining engineers. We shall confine ourselves here to simply mentioning the centrifugal or rotary pump. These pumps, which have been introduced comparatively recently, and appear likely to be largely used, are somewhat like turbines; they suck up the water at the centre and throw it out against the circumference of a hollow cylinder which carries a delivery pipe. The water is forced up in consequence of the pressure produced on the circumference by the rotatory motion, and this pressure increases with the velocity with which the pump is turned.

Without entering into other details, we will merely point out that the rotary pumps have a decided advantage for lifting muddy water, as no tight packing is required; with a given power their useful effect increases with the volume of water to be raised, but it diminishes as the height of the lift becomes greater.

As a rule a mine manager has not to trouble himself with making these metallic pumps; they are to be found ready-made in great variety, and of different sizes, according to the delivery and height of lift required.

In most cases these pumps are worked by hand, but if more power is required horse-gear can be used, or compressed air can be applied to work them, as pointed out in No. 421.

(526) We will now suppose that at last the water has reached the pumping-shaft, and has to be raised to the surface or to an adit level. Just as in the case of winding machinery, we have to consider, firstly, the *motive power* and its *receiver;* then the *transmitting organs;* and, finally, the *acting parts,* by means of which we obtain the industrial result we aimed at.

It by no means follows, *theoretically,* that because a mine is deep and extensive it must be troubled with water, and that something more than animal power will be required for pumping, as is the case for winding; indeed it is easy to imagine such a mine having very little water. However, we will merely say, that should an occasion arise where nothing but animal power is available, there would be

no difficulty in converting the rotatory motion of a windlass worked by men, or of a whim worked by horses, into a reciprocating motion for pumps; we shall see how this is effected in the case of water-wheels. Where animal power is insufficient we have recourse to water or steam. A fall of water, whether natural or created artificially by an adit, may be utilized theoretically by any of the known hydraulic motors; but when the power has to be applied to working mine pumps the choice of the machine is not always a matter of indifference. The amount of fall that can be utilized by an overshot water-wheel is limited by the diameter which can be given to such a wheel in practice. If the fall is sufficient with the quantity of water at one's disposal to develope the requisite amount of power, overshot wheels may be employed with advantage, aud their slow speed is generally suitable for the reciprocating motion which has to be imparted to the pump rods.

The power is usually conveyed from the wheel to the pumps by means of connecting rods, *flat rods,* and *bobs.* The pumps themselves are worked by rods fixed to one main rod balanced by proper counterpoises, or to two main rods which balance one another. In the latter case the pumps are attached alternately to the main rods, and so form two systems which raise the water in alternate lifts.

This constitutes, as it were, the standard arrangement which was for a long time in use in most of the metalliferous districts in England, but more particularly in Germany.

Figs. 411 and 412, taken from *La Richesse Minérale,* give an illustration of it. The former shows the general arrangement, and the latter explains the principal details; but of course these may be varied considerably.

Even at the present day there are many places where pumps are worked in this manner. The defects of this system are, that it cannot utilize a very high fall; and secondly, as already stated in No. 445, there is a great loss of power when the line of flat rods is long and bent in several places, either horizontally or vertically.

Perhaps we may be right in thinking that these rigid rods for transmitting power might be replaced with advantage by Hirn's arrangement. A water-wheel setting in motion a pulley

carrying an endless wire rope properly guided along its course, can be made to drive another pulley fixed on the crank-shaft working the pump rods.

Perhaps also, in order to reduce the strain on the rope, as well as to lessen the friction and avoid the chance of the rope slipping, it would be advisable to fix the driving pulley to a special shaft and work it with multiplying gear, whilst the speed of the pulley at the other end, also carried on a separate shaft, would similarly have to be reduced by gearing. This system, though somewhat complicated in appearance, would in reality be simpler, and would work with less passive resistance, than the series of rigid rods, in all cases where there was a considerable distance horizontally and vertically between the water-wheel and the point of attachment of the pumps to the cranks.

Turbines differ from water-wheels in being capable of utilizing *any amount of fall;* but their angular velocity, which for a given amount of power increases with the height of the fall, is generally much too great for them to be applied directly to pump-rods. In using turbines, therefore, for driving Hirn's arrangement just referred to, we should have to do exactly the reverse of what we proposed in the case of water-wheels, and employ gearing to *reduce,* and not to increase, the velocity.

Although the turbine has the advantage over the overshot wheel of being able to utilize all or any desired portion of a given fall, it is contended on the other side, especially in the case of a high fall, that its small mass renders it unfit for actuating parts of machinery with an irregular and intermittent motion, like a connecting-rod or a pump-rod worked by a crank. However, the smallness of the mass may be compensated for by the speed, and there is no reason why the shaft of the turbine should not be provided with a fly-wheel having any desired moment of inertia.

As is well known, there is another machine capable, like the turbine, of utilizing any amount of fall; viz., the water-pressure engine. It may be *double-acting* or *rotary,* or *single-acting.*

The first kind of water-pressure engines are used to impart a rotatory motion to a shaft with a fly-wheel, from which power is taken just as it is in the case of an overshot water-wheel or turbine.

It will, therefore, generally carry the cranks directly, or if its angular velocity, which is usually greater than that of an overshot wheel, and less than that of a turbine, is not fitted for direct action, then multiplying or reducing gearing, according to circumstances, must be introduced between it and the crank-shaft of the pumps. As may be naturally supposed, this is not the best solution of the problem that can be offered. For utilizing a high fall nothing can be better than a single-acting water-pressure engine with its piston-rod attached directly to the pumps, just as the double-acting machine is the best for winding. (See No. 435.)

For working pumps it has the double advantage over the rotary machine of being simpler and of doing a higher duty, because there are no intermediate parts between the piston *receiving* the power and the plunger which *acts* in the pump, excepting the main rod itself. Like turbines, it is capable of utilizing any amount of fall, and it has the same advantages over them as over the rotary water-pressure engines. Furthermore, it can easily be erected anywhere, either at the adit level or below it. (See *Cours de Machines*, Nos. 274, *et seq.*)

(527) If water-power cannot be had at all, or only to an insufficient extent, and if animal power is out of the question, we are obliged to have recourse to steam.* It may be employed in various ways.

Where the quantity of water to be raised is small, the ordinary *winding machinery* of the mine may be utilized while not employed for its principal object. This system (which is applicable with all other motors as well as steam) is often adopted in large collieries, which in other respects are provided with the best appliances, but have no other means of getting rid of their water than by drawing it up in barrels from time to time, or perhaps every day, in the interval between two shifts, with the aid of their winding machinery. Sometimes large tanks are placed in the cage like the trams, or else the cage is taken out and a large special tank

* This is not strictly correct, as wind-power is also available, and is sometimes used; as for instance at the Mona Mines, Anglesey, and Clogau Mine, in Merionethshire.—*Translators.*

put in, fitting into the guides like the cage itself. Tanks are filled by being lowered into the sump, when a valve in their bottom is lifted up by the water. On reaching the surface the water is discharged by means of various simple contrivances, some of which are represented in figs. 413 to 415. (See explanation of the plates.)

For instance, the tank may be lowered on to a carriage run in over the pit, and so arranged that just as the tank comes to rest upon two beams the spindle of the valve touches the bottom, is lifted up, and allows the water to escape. Or else the valve may be made to open automatically when the tank reaches the surface.

If, on the other hand, a water-barrel is employed without guides, it is lowered on to a movable piece of timber pushed in over the shaft at the landing-place, and so arranged that the barrel does not rest upon it fairly, but turns over and empties its contents into a trough placed a little below the edge of the pit.

In all these cases the barrels are emptied without being unhooked from the ropes.

This mode of drawing water may be carried on not only with the ordinary winding machine, but also by a special machine of the same nature not used for anything else. This system enables us to make use of the plant of an old pit, when it is no longer required for winding mineral.

It is admitted that it takes no longer to wind up water than mineral, indeed, not so long, as the loss of time between two operations is less in the case of water. The winding machine, or a special machine of the same class, may therefore be employed when the *quantity of water* to be lifted is comparable to the *amount of mineral* to be raised, and is either equal to it or two or three times greater. This system is the cheapest as far as first cost is concerned, and if it is sufficient, as will be very often the case in collieries at least, it may be looked upon as not unreasonable.

But in many instances it will not suffice, either when the mines are very deep, in which case, as we have pointed out, the difficulties of winding are increased, or when the quantity of water to be raised is very great. Mines might be mentioned where the weight of water

to be raised is 10, 15, or 20 times greater than that of the mineral extracted.

(528) Instead of drawing the water by the winding-engine, or by a special machine of the same kind, we can employ one of the following arrangements:

1. A special crank may be fixed to the fly-wheel shaft of the winding-engine, with a connecting-rod working one or two pump rods, in the manner explained in the case of the overshot water-wheel. Pumping and winding will then be carried on simultaneously. But the intermittent action and change of direction of a winding engine are not suitable for pumps, and this system is not applicable, unless the pumping is a matter of small importance compared with the winding.

2. A stationary or portable rotary engine, according as the work is permanent or temporary, may be fixed near the pumping shaft, either at the surface or at the adit level, and made to work a single rod or the double rods of a succession of pumps in the manner just explained. In this case there are two essential differences, however; firstly, there is no limit to the power that can be employed, as there is when the winding machine is used; and secondly, as the engine can be erected anywhere, the flat rods, usually required with overshot wheels, can be dispensed with.

3. The rotary engine may be put up at the bottom of the shaft, where it can draw up the water directly from the *fork* or *sump*, and force it to the surface in one lift.

This plan has the advantage of getting rid of the cumbrous and expensive rods with the series of pumps and their stays in the engine-shaft, and of reducing the whole affair to a mere line of pipes occupying only a very small space in the shaft, which can consequently be used for other purposes than pumping. At the same time the cost of keeping a long run of pumps in order is obviated, and this is a matter which, as a rule, requires much attention, and gives a great deal of trouble.

This system has been adopted in several instances at the Blanzy mines, and M. A. Burat noticed one example in his *Matériel des Houillères* in 1861, and gave some more minute

details in his *Traité d'exploitation* (1871). A general view of the second machine is shown in fig. 416, which was designed and erected with the greatest care by M. Audemar, to force the water in one lift to a height of 328 yards (300 metres).

The first cost of this machine was certainly less than that of an ordinary set of pumps worked by rods, and, thanks to good workmanship, it is probably not more expensive to keep in order. But the principal obstacle which lies in the way of this system becoming general is the fact that the pumps and delivery pipes are subjected to enormous pressures (reaching 30 atmospheres), and consequently all the parts have to be very strong, and fitted together with the greatest nicety. Besides, where an engine is worked underground it is less easy to watch it properly; and another inconvenience is, that it is exposed to movements of the ground, which might cause joints to give, and do damage increasing with the amount of pressure.

No doubt a single lift of 328 yards (300 metres) is already pretty considerable, although we may find force-pumps acting against a load of water equal to 546 yards (500 metres) and more in certain industries, such as in making patent fuel, in working Armstrong's accumulators, and also in certain salt works in Bavaria. At all events, with our present appliances the system could not be employed in mines where it would be necessary to have a single lift of more than 546 yards (500 metres).

4. As a variety of underground pumping-engines we may mention the special system first brought out in America, and which is spreading also in England, which consists in having direct double-acting horizontal engines without a fly-wheel or any parts having a rotary motion.

These engines are regulated by levers and tappets fixed to the piston-rod; and the piston-rod itself is attached directly to the plunger of a double-acting force-pump on the same bed-plate. The receiving and the acting parts are thus reduced to their maximum of simplicity and compactness; and the engine can be erected in an excavation of small dimensions without any of the difficulties and inconvenience caused by having to find room for a fly-wheel and provide proper bearings for its journals.

These pumping machines may be very useful in cases of emergency; for instance, if it were necessary to fix an engine in the shortest possible time for draining an unexpected influx of water. They consequently answer admirably for the purposes of many American mines, as the proprietors are not always able, or do not even care, to conduct their operations with the proper amount of foresight and completeness, and think nothing so important as rapidity of execution. From a *purely technical* point of view these machines have little to recommend them theoretically; the absence of any mass *acting like a fly-wheel*, whether the rim of a true fly-wheel or a long length of rods, prevents the use of expansion, and where extreme simplicity is required condensers are not available. These machines bear about the same relation to a good fixed pumping-engine, where the steam is employed in a sensible manner, as a high-pressure non-condensing engine worked without expansion does to an improved Woolf's engine.

(529) The fifth and last type of steam-engine for pumping is the single-acting engine worked like the single-acting water-pressure engine; *i.e.* one which imparts to the pump-rod a reciprocating motion like that of its own piston.

This is the plan which has been adopted for the largest pumping engines in English metal mines, and in some of the metal and coal mines of the Continent. It is the best system for very wet mines, and it is applicable for the greatest depths and for the greatest bodies of water. Under this head we find the so-called *Cornish engines*, famous for being worked with an exceptionally small consumption of fuel. The ordinary Cornish engine may be defined as :—

A single-acting, condensing, beam-engine, for steam of high or medium pressure, with a high rate of expansion regulated by hand, with valves worked by tappets on a plug-rod, and with an intermittent action regulated at pleasure by a cataract.

In an engine of this kind the steam acts on the top of the piston, forcing it down, and at the same time raising the main rod attached to the other end of the beam.

First of all steam is let in at full pressure, and imparts an accelerated motion to the whole system. It is then cut off at some

suitable point in the stroke—the motion is still accelerated until the pressure of the expanded steam is equal to the total of the resistances of the machine. From this moment, which is that of the maximum velocity, the speed gradually slackens; the excess of the resistances above the pressure gradually destroys the *vis viva* of the parts, and the steam ought to have been cut off at such a point that the piston arrives at the end of its course with a velocity equal to zero.

The down, or *in-door*, stroke being ended, communication is set up between the upper and lower faces of the piston, and as soon as an equilibrium is established the piston ascends, as it is drawn up by the weight of the rods, which force the water sucked up during the down stroke of the engine into the column of pumps.

The up, or *out-door*, stroke is brought to a close by shutting the equilibrium valve at the proper moment and thereby creating a resistance, and by the compression of the steam above the piston. It comes back therefore to the starting-point with a velocity of nothing.

All the parts of the machine are then at rest, save the *cataract*, which has been regulated as required. It prepares for the next stroke by *first* opening the exhaust valve, which puts the steam under the piston in communication with the condenser, and *the instant afterwards* it opens the steam-valve which lets in steam from the boiler on to the top of the piston.

This is the ordinary mode of action of the Cornish engine, the exceptionally favourable results of which were brought forward by M. Combes more than thirty years ago. These results are due not only to the fact that the steam is employed *under the best theoretical conditions*, but also for the following reasons; viz., the engines are large, and every minute precaution is taken to prevent escapes of steam and loss of heat by radiation; and, further, the amount of passive resistance is small, owing to the simplicity of the machinery and the almost direct connection between the engine and the principal resistance.

Fig. 417, extracted from M. Combes' work, gives a general view of a Cornish engine, an old one it is true, but constructed on a good design, and of a type still much in use.

(530) Although Cornish engines are very satisfactory, some changes from the ordinary type may be made with advantage.

In the first place we may remark that the plan of having a single-acting engine giving a series of strokes separated by intervals of complete repose is not the only solution of the problem.

It is easy to conceive that a Cornish engine may be turned into a double-acting rotary engine by altering the valve-gear, and adding a connecting-rod and crank driving the shaft of a fly-wheel. This is the modification which blowing-engines have generally undergone; they were originally engines with a reciprocating motion regulated by the action of a governor having a floating piston; but they have now become rotary-engines having a continuous motion.

If this system were adopted, the main rod would have to be attached either to a suitable point on the beam or else to a crank keyed on the fly-wheel shaft. The rod would have to be balanced so that the resistances to be overcome during the up and down strokes should be sensibly equal, and the fly-wheel might be made with a small moment of inertia, just enough to get over the dead point, but without endeavouring to make the rotatory motion unnecessarily regular. A machine of this kind, acting under the same conditions of pressure, expansion, and condensation as a Cornish engine, is in nowise inferior to it theoretically. In fact this system seems to be coming into favour at the present time, and it has been applied in several instances, especially in Germany.

It must be admitted that it presents a certain advantage from the fact that the reciprocating motion of the piston is regulated by its direct connection with the fly-wheel; the result is that the piston may be worked safely at a higher mean velocity, and, either in consequence of this higher speed or from giving up the cataract, the piston can be made to give a greater number of strokes per minute; in other words, the dimensions of the engine for a given expenditure of steam may be reduced. We may further add that this system does away with all necessity of adding great masses to the main rod, which are put on in other systems in order to enable the engine to be worked with a high rate of expansion.

The rotary system seems to us perfectly warrantable when the strength of the machinery does not exceed certain limits. But when the load is very large, either on account of the quantity of the water or the great depth from which it must be lifted, and when, consequently, the main-rod is very heavy, we shall scarcely be wrong in thinking that the Cornish engine is mechanically preferable as a permanent pumping machine, and for the following reason; viz., there is a marked period of repose between two successive strokes of the engine which allows all vibrations to subside, and so tends materially to keep all the parts in order, and lessen the wear and tear.

While we consider that the Cornish system of pumping machinery still appears at the present day to be the best fitted for heavy work, we must, at the same time, point out some other modifications. These do not relate, like the last one, to the mode of action of the steam in the cylinder, but they are nevertheless of some practical importance.

The first variation, which is much in vogue on the Continent, consists in doing away with the ponderous beam and making the engine *direct acting*. The cylinder is placed vertically above the prolongation of the axis of the main-rod, and the motion of the steam is reversed. The pressure of the steam *raises the piston*, and the equilibrium valve acts *during the down-stroke*. Except for this alteration the direct-acting, or Bull engine, works exactly like the ordinary Cornish engine, and is noways inferior to it theoretically.

Fig. 418 represents one of these engines, and by comparing it with the preceding one an idea will be obtained of the characteristic differences of the two types.

The object of adopting Bull's type of engine is to reduce the cost of erection. With these engines there is no necessity of building high and strong walls to carry the supports of the beam for which great strength is required, because during the down-stroke, for instance, the total weight to be supported is evidently equal to twice the load of the pumps, supposing the two parts of the beam to be of the same length. Besides this also, the foundations for the cylinder may be less extensive, because the steam tends to *press it against* its bed instead of tending to *lift it*. On the other hand

the position of the cylinder obstructs the mouth of the shaft to some extent, and renders it less available for other uses. The inconvenience caused in this way may be considerable if the cylinder is large and the shaft small.

Lastly, in the case of a fiery colliery, the engine would be liable to suffer greater injuries from a large explosion than if it were placed in a house adjacent to the shaft. In each particular instance these advantages and disadvantages will have to be duly weighed; but we must bear in mind, we repeat, that the *duty* for a given consumption of coal ought to be the same for the two kinds of engine if they are applied to the same work in pumping, and have to *set in motion equal masses.*

On the Continent the Bull engine is preferred; but in England, on the contrary, the beam engine is most esteemed, and all its details have been brought by long practice to a high degree of perfection.

It seems to us that Bull engines have the greatest future before them, since they are less costly to erect, and because the question of consumption of fuel does not enter into the calculation in making the choice between the two machines.

(531) There are, however, two varieties of engines which have been designed mainly with reference to this question. The first modification consists in employing Woolf's system of expansion in a second cylinder, and it is applied both to Cornish engines and Bull engines. It has been shown that working expansively with two cylinders has the two following advantages: Firstly, it gets rid of the influence of the residual space, which cannot be neglected with a high expansion in a single cylinder; and, secondly, *for a given degree of expansion*, it reduces the ratio between the *initial force* and the *final force* (see *Cours de Machines*), and to produce *a given mean force* (which ought always to be the same, and equal to the load) the *initial force* may be *smaller*. The result is that for a given mass which has to be set in motion the initial acceleration is less, and consequently the force of inertia plays a less important part, and the whole of the machinery is exposed to smaller strains.

Thus, *for a given rate of expansion and with the same masses to be set in motion*, the compound engine works more smoothly, or, what is the same thing in another form, *supposing we admit a given amount of strain for the various parts*, the engine can be worked with a higher rate of expansion, or the masses to be moved *may be less* than with a single cylinder.

This advantage of having two cylinders, as it has just been enunciated, appears sufficient to completely justify the adoption of Woolf's system, in spite of the fact that compound engines are more complicated, and more expensive originally. The advantage of using them increases as the power of the engines becomes greater, and the price of fuel higher.

There are two types of these engines. In the first, one cylinder is *placed above* the other, and both are set up along the prolongation of the axis of the main-rod, and here, of course, they have the same stroke, and differ only in diameter. In the second, the cylinders are placed *side by side*, as is usually done with most of Woolf's double-acting engines; and in this case the stroke and diameter of the first cylinder are less than those of the expansion cylinder.

It is now more than forty years since the first Woolf engine was erected in Cornwall; but the system has not made any headway there. An interesting example of the second type was put up about ten years ago by M. C. Kley at the Vieille Montagne mines. It is shown in fig. 419.

In our opinion this system is destined to come more generally into use, as it becomes more imperatively necessary to economize fuel on account of its rise in price.

(582) The second modification is the invention of M. Bochkoltz The object of it is to correct a defect first pointed out by M. Bochkoltz, which usually exists in pumps working with clacks, but which is not of any importance excepting when the pumps are very large. Expressed in the most general way this defect is as follows: If we take the case of a main rod actuating a piston which forces water up a rising main, the load on the rod is equal to the weight of a column of water with a base equal to the area of the piston and a

height equal to the difference of level between the piston and the top of the water. But at the moment of starting it is necessary that the rod should exert a very much greater pressure (leaving out the question of inertia) in order to overcome *a resistance of a special nature;* viz., the resistance opposed by the clack at the base of the column while being opened. It is due, not to the weight of the clack, which may be neglected, but to the fact that the pressure of the piston is exerted against the lower face of the clack, whilst the pressure of the column acts on the whole of the upper surface, which exceeds the first by the amount of lap of the clack on its seat.

This is not a mere theoretical remark without any practical bearing. The difference of area between the two surfaces is quite comparable with the area of either of them alone. The diameter of the clack is measured in inches, and so is the width of the lap; this lap or border cannot be very small, especially when the column is high, because, otherwise, the pressure upon it would destroy it rapidly. We are well within the mark if we estimate that the area of the lap is one-fifth of the area of the valve; consequently, *the initial pressure* of the rod must be one-fifth greater than *the pressure required during the rest of the stroke.* The difference will be insignificant if these pressures only amount to a few pounds; but it is quite another matter if they are measured by hundredweights, and if this difference is repeated several times on account of there being a series of successive lifts of pumps.

In a case of this kind it may be necessary, *in order to open* the clacks, to make the main rod very much heavier than would be required *for keeping them open and forcing up the water.* This excess of weight requires the expenditure of a certain amount of motive power to raise it, and as soon as the rod in its descent has opened the clacks, it becomes useless and even injurious. In fact it becomes necessary to counterbalance it, so that the rod may not acquire an accelerated velocity; this can only be effected in practice by wire-drawing the steam through the equilibrium valve, and so creating a difference between its pressures on the two sides of the piston, which compensates for the excess of weight. Here the steam acts against the load as a brake or check instead of as a

motive power. The throttling of the equilibrium valve is not in reality a remedy; it is a mere palliative, which *masks* the defect but *does not correct* it, for the motive power expended in raising the extra weight of the rod is entirely wasted. With a view to remedy this evil, M. Bochkoltz invented the contrivance called the *power-regenerator.* It is very simple and effective, and consists in a sort of pendulum, attached so that it oscillates when the rods move. The pendulum is usually an arm fixed at right angles to the balance-bob and provided with a heavy weight at its extremity. It stands in a vertical position when the balance-bob is horizontal, or the steam piston at half-stroke, and it is inclined one way or the other when the piston is at the end of a stroke.

At the beginning of a stroke it acts as *a motive power,* because it is falling towards a vertical position, whilst towards the end of a stroke it acts as a *brake,* because it is being raised up. By properly regulating the length, weight, and initial inclination, we can produce at the proper time a strain on the rod equal to the excess of weight just referred to.

When the clacks have been opened, the pendulum helps to accelerate the velocity for the first half of the down stroke of the pump, and to check it during the second half. An analogous effect is produced during the ascent of the rod; the pendulum tends to accelerate the motion at first, and then to retard it.

Besides affording the benefit of doing away with all useless expenditure of motive power, the pendulum has a further advantage of a different nature, which is nevertheless not without decided practical importance. As the regenerator acts as a motor at the beginning of a stroke, and as a brake at the end, it enables us to increase the velocity to a certain point, or to destroy it within the limits of a *smaller fraction of the stroke.* It follows from this that the mean velocity may be greater, because the piston *can travel with greater speed* during *a longer portion of its stroke.*

We are, therefore, able to increase the number of strokes per minute, and to take advantage of this for *diminishing the dimensoins* of a new engine that has to be put up, or for *increasing the power* of an engine already erected, which is beginning to be overleaded. In both of these cases the Bochkoltz regenerator is

capable of rendering very great service, and it is well worthy of the attention of engineers.

Figure 420 represents a Bull engine, erected by M. Quillacq, and furnished with a regenerator designed by the inventor.

The main-rod weighs 108¼ statute tons (110,000 kilos.), the column of water in the pumps 75¼ tons (76,500 kilos.), and the plungers are 20·8 inches ($0^{m}\cdot53$) in diameter; the balance-bob has been taken at 28 tons (28,500 kilos.), and the regenerator 77¾ tons (79,000 kilos.), acting with a leverage of 16 feet 4 inches (5 metres); the engine makes seven and a half strokes per minute, and the length of the stroke is 9 feet 10½ inches ($3^{m}\cdot01$).

(533) Summing up what has just been said (Nos. 530 to 532), we arrive at the conclusion that the Cornish system of pumping-engines, which has already reached such a high degree of perfection, appears to admit of the following alterations:

1. To omit the beam, as used by Watt, and make the engine act directly, so as to reduce the cost of erection without diminishing the economy of working.

2. The adoption of Woolf's double cylinders, in order to increase the *duty* by employing a higher rate of expansion, or to diminish the strain on the engine, or to reduce the size of the parts to be set in motion for a given rate of expansion.

3. The adoption of the Bochkoltz regenerator in order to increase the work done by the steam, by reducing the quantity used as a resistance, or to increase the power of an engine by enabling it to be worked with a more rapid stroke.

We cannot help thinking that, in the present state of engineering science, there is no better prime mover for large pumps than an engine designed on these principles, provided that it is well-proportioned, so as to prevent any wire-drawing of the steam, that it is supplied with the best contrivances for preventing the escape of steam and condensation, and that it sets in motion bodies of sufficient mass. We shall not devote any more time to the consideration of the different kinds of motive power which can be employed for pumping. We must confine ourselves here to the general mention of them, and take it for granted that our readers

are acquainted with the details of the machines by which they may be utilized; if not, we may refer them to the *Cours de Machines*, which contains a description of them, and of the means of calculating their dimensions.

It now remains for us to say a few words on the pumping machinery which the prime movers set in motion. It is not necessary to allude again to water-barrels drawn up by winding machinery, or to direct-acting force-pumps of ordinary construction fixed underground in the manner mentioned in No. 528, we have merely to deal with ordinary *mine pumps* actuated by reciprocating rods working in the pumping-shaft (*engine-shaft*, Cornwall).

We distinguish *lift-pumps* in which the water is raised during the ascent of the rods by a drawing action, and *force-pumps* in which the action is reversed; that is to say, the rods in descending tend to compress the water, and so force it up the column of pumps.

Figure 421, which is described fully in the explanation of the plates, shows examples of these pumps—A, B, C, D. The first three are lifting-pumps; the first has a *hollow piston* or *bucket*, the second a *solid piston*, and the third a *plunger*. The fourth diagram represents the ordinary arrangement of a force-pump with a plunger.

It may be noticed that, theoretically, there is no limit to the length of pipes which can be placed either above the hollow piston, or above the clack of the force-pump.

The name *low-pump*, whether lifting or forcing, is given to any pump when the height to which the water is raised is about equal to that which measures the pressure of the atmosphere, or not much greater; the name *high-pump* is applied when the height is equivalent to several atmospheres.

The separate pumps in an engine-shaft are placed one above another; each set constitutes a *lift*, and the water is raised from the *sump* or *fork* to the surface by several repetitions of the same process.

There are two entirely distinct methods of working the pistons, according as they are set in motion by a double-acting rotary machine (water-wheel, or steam-engine), or by a single-acting machine (driven by steam or water).

In the first case the usual arrangement, as already pointed out, is to have two main rods reciprocating in contrary directions, and mutually balancing each other. Secondary rods are fixed to them, and these work pumps, arranged alternately, on each side. Water is, therefore, always being raised, and the resistance is regular. The rods, which would not be strong enough to force the water, draw it up during their upstroke. The pumps, as a rule, are lift-pumps, with a hollow piston or bucket, and the rods are placed inside the column, as shown in fig. 421A.

The single main-rod, however, may be used with rotary machines, and *it will work just as regularly as two,* provided that we counterbalance, with a beam and counterpoise, the *total* weight of the rod and *half* the load of water raised during its upstroke. The strain on the machine is, therefore, the same during the up-stroke as during the downstroke.

(534) In the second case, that of the single-acting engine, a single rod only is employed, and it is attached either directly to the piston, or to one end of a great beam worked by the piston. If absolutely necessary, this main-rod might lift the water during its upstroke, as just described in the case of rotary machines, and descend by its own weight; but this weight would have to be nearly entirely balanced by a counterpoise. It is much simpler to employ the engine to raise the rod, and let the latter force the water up by its descent. The water then acts as a counterpoise.

This arrangement, which is shown in fig. 421D, is that which reduces the pump to its maximum degree of simplicity. There are simply two valves to be kept in order, and a stuffing-box, which affords an immense advantage over a solid or hollow piston moving in a bored *working barrel.* This is a very suitable plan, provided that the rod is sufficiently rigid, and that care is taken to limit the amount of compressing strain to which it is subjected, and to distribute this strain judiciously.

Theoretically, even a large rod could not act by compression unless it were properly guided, or else were very short. We must, therefore, suppose the main-rod to be divided up into as many distinct portions as there are separate pumps, and arrange that each

portion may, *on its own account* in some measure, force up the water in its own lift. If any portion of the rods is too light it must be loaded with iron, and if it is too heavy it must be balanced by a counterpoise (*balance-bob*).

In this manner the load on the engine is, theoretically, ***independent of the weight of the main-rod;*** it depends solely on the weight of the column of water to be raised. During the ascent of the rod this load is equal to the weight of the water, during the descent it is *nil.* In the same way, during the upstroke the tension at the junction of any two portions into which we may suppose the rod subdivided, depends simply on the weight of the column of water in the lifts below, and during the downstroke it is nothing.

It is evident that if all the lifts are of equal height, and have plungers of the same diameter, the section of the main-rod at any point is proportional to the number of lifts below that point. The square of one of the dimensions of this section is thus proportional to its height above the lower part of the rod. If, then, we were to make a vertical section of the rod, the profile would be a parabola, as was pointed out in No. 488 for the rod of a man-engine; we may therefore deduce a similar conclusion, that pump-rods may be made very long indeed without its being necessary to increase the section nearly so rapidly as we have to do with winding-ropes. The reason of this, we repeat, is that the load or strain at its point of attachment *does not depend* on the weight of the rod, or rather it *depends on that element only in so far as it is used to force up the column of water.*

This regular subdivision of the compressing action along the main-rod is not strictly adhered to in practice, but it is advisable to carry it out as far as possible. In designing *pitwork*, care must also be taken to ascertain how the strains are distributed along the main-rod, or in what manner the rod works in each lift, whether by *tension* or by *compression*, both during the upstroke and the downstroke.

The lifts and the size and position of the balance-bobs should be planned, so that the strain in no place exceeds a given limit, and so that there may not be too great a tendency in the rod to

vibrate or sway sideways. We may remark that we can always do away with this vibration by arranging that the rod shall not act anywhere by compression. All that is requisite to effect this is to arrange that any one plunger shall be drawn down by the weight of the main-rod *below it*, and not by the weight above it, that the rod, in fact, shall be *pulled* and not *pushed* during the downstroke.

In this case the strain on the rod and its joints is constant in *direction*, though not in amount; and this is a more favourable state of things for preserving the joints in good order than if they were liable to getting a little play from being subjected alternately to tension and compression. A main-rod arranged in this way might in some measure be replaced by a *flexible* connecting medium, such as a rope with plungers attached to it, provided that the portion of rope between two plungers were heavy enough to force up the water above the upper one.

(535) We shall now add a few details concerning the manner of fixing the various parts of pumps such as we have just referred to. The whole of the machinery should be erected on a much more powerful scale than what is required at first, because it is necessary to make provision for a regular increase in the influx of water as the workings are developed, as well as for the chance of an abnormal influx.

In arranging pitwork the following points should be attended to. The machinery must be simple, and the individual parts firm, without excluding a certain amount of independence, which permits the pitwork to yield to any accidental movements of the ground; there should be easy means of access to all parts for the purpose of inspection and repairs, whilst at the same time the size of the pumping compartment should be kept as small as possible; lastly, provision should be made for the case of the bottom lift being entirely covered with water in consequence of a long stoppage.

The best way of satisfying these conditions is to arrange that the main-rod and all the secondary rods shall be in one vertical line, that the different working pumps, or *plunger cases*, shall all

be in the same line, and the different columns of pumps vertically one above the other. Lastly, the bottom lift should be a drawing-lift with a *bucket*, and all the other lifts should be force-pumps (*plunger-lifts*). By arranging things in this way the whole of the strain is exerted along the axis of the main-rod, without giving rise to any side strain, which would tend to bend it or make it vibrate. The room required for the whole of the pitwork is reduced, in plan, to the space occupied by the bearers which support the columns of pumps. The bottom lift may be covered with water, provided it has been arranged so that the bucket and stationary-valve (*clack*) can be changed under water. Finally, during the downstroke of the main-rod, the upper lifts, which are force-pumps, utilize the motive power required to produce the upstroke.

In a complete set of pumps we distinguish the drawing-lift, the plunger-lifts, or force-pumps, the columns of pumps or rising-mains, the main-rods, the secondary-rods, the balance-bobs, the bearers, the contrivances for guiding the rod, and limiting the length of stroke, and finally, sundry accessory arrangements.

(536) *The bottom-lift, or drawing-lift.*—The suction-pipe (*wind-bore, snore-piece, tail-piece*) of this pump dips into the *sump* or *fork*. It is enlarged at the end, closed at the very bottom, and provided with holes at the sides, which prevent large chips or stones from being sucked in.

It is a good plan not to allow the mine-water to run straight into the *fork*, but to carry it first into a reservoir large enough to hold two or three days' supply, and there to let it settle and deposit any sediment.

This reservoir, or *lodgement*, is merely a gallery, or a cross-cut, driven below the regular bottom level, which can be put into communication with the shaft by means of a pipe provided with a large stop-cock worked from the *plat* (*hanging-on place*). Near the place where the water enters the reservoir there should be two partial partitions, one at the bottom to catch *all foreign substances heavier than water*, and the other at the top to catch all *floating bodies*.

The suction-pipe reaches up from 13 to 16 feet (4 to 5 metres)

higher than the usual level of the water in the *fork*, and is followed by the clack-piece with a seat, in which is placed the suction valve (*clack*). It is best not to fix this valve permanently, as then it can be taken out through the door for repairs or renewal. The clack is furthermore provided with a loop, by means of which it can be fished up with a hook lowered through the column of pumps and working barrel, after the bucket has been drawn out. This operation must be carried out if the valve has to be changed while the pump is under water.

The valve-chamber, or clack-piece, is an enlarged part of the pump placed between the suction-pipe and working-barrel, and provided with a door, by means of which the clack and bucket can be examined, and the clack taken out to be *re-geared* with leather. The clack-piece is exposed to a considerable strain; for the inside of it is subjected alternately to a *negative* pressure during the ascent of the rod, and to the whole pressure of the column of water in the rising main whilst the bucket descends and its valve is open.

The *working barrel* in which the bucket moves, is placed vertically below the rising main. It is carefully bored, and generally made of cast iron; but occasionally gun metal is employed, or else the barrel is bushed with gun metal when the water is acidulous. The working barrel should be slightly bevelled at the top and bottom, to allow the bucket to be easily removed either through the rising-main or the clack-piece.

The bucket is usually *geared* with a band of leather, which slopes out upwards, and is pressed against the sides of the working barrel by the weight of the water. It carries a valve, which is also made of leather, and is hinged along the diameter so as to form two half valves. These are stiffened by having semicircular plates of iron or gun metal riveted on to them. Nowadays the leather is often replaced with advantage by vulcanized india-rubber.

Above the working barrel, and vertically in a line with it, comes the series of pumps; their diameter should not be less than that of the bevelled end of the working barrel. Theoretically, as we remarked in No. 533, there is no limit to the height of these

pumps. It is generally 20 to 27 yards (20 to 25 metres), and never exceeds 43 yards (40 metres). The greater the extent of the workings the less is there any necessity for having a long lift, because in the case of a stoppage a greater length of time will elapse before the first plunger-lift is in danger of being drowned.

Figure 422 represents the general arrangement and the principal details just described. This is the plan most frequently met with. The only alterations proposed relate to the details, especially the *gearing* of the bucket and the valves, with a view either to make them act better, or to afford more waterway. For this purpose metallic double-beat valves may be employed, like Hornblower's valves used in large steam-engines; but this arrangement is suitable only for clear water.

Instead of a single valve, several partial ones may be employed hinged on the circumference, and opening simultaneously. (Fig. 423.) These valves offer less obstruction to the waterway than two semi-circular valves hinged along the diameter; and the waterway afforded by a given angular motion of the valves increases as their position when at rest approaches nearer to the vertical.

These rigid valves may be replaced by a dish-shaped piece of leather or gutta-percha resting on a metal seat, perforated with numerous openings. The leather is cut obliquely in several places along the circumference, so that the edge may lift readily and let the water pass.

Figure 424 shows a bucket with a valve on this system, known as Letestu's valve. It is considered very satisfactory for pumping water which happens to be rather muddy. The principle is just as well adapted for clacks as for buckets. (See Explanation of the Plates.)

(537) *Upper-lifts or Force-pumps.*—These are always made with plungers, and they are arranged so as to make the descending weight of the rod force the water up. These pumps have a great advantage in admitting the use of plungers working in stuffing-boxes, which do not rub against the sides of the *plunger-case*. This plan is much preferable to buckets with valves, which require bored working barrels. The construction is greatly

simplified, repairs can be executed with greater ease and rapidity; and lastly, and this is the essential point, the mere inspection of the stuffing-box reveals at once when the packing is loose, and the defect can be remedied immediately by tightening the bolts which keep down the gland. With a bucket there is nothing to indicate a want of repairs except a diminution in the delivery. This may not always be noticed at once, and in the meantime the total delivery falls off, because it is not greater than that of the worst lift; and finally, when the defect has to be remedied, the engine has to be stopped for some time.

We may add that, with more or less muddy water, such as is often met with in mines, the packing in a stuffing-box lasts much longer than the leather, or india-rubber, outside a bucket, so that the former system renders the repairs not only more simple and easy, but also very much less frequent.

Lastly, we may remark that the plunger system allows us to work with greater pressures than are compatible with buckets, because the *gearing* of the latter chafes a great deal, and is quickly worn out if the load is heavy.

The consequence is that plunger-pumps have the advantage, that they can be placed further apart than lifting-pumps, or in other words, the number of lifts may be diminished.

As a rule, the height to which the water is sucked up in a force-pump is small. The water is drawn through a short windbore standing in the reservoir which receives the discharge of the lift below.

The reservoir is a large cistern, made of sheet iron or timber, and carried by the same bearers as the pump, or partly lodged in a niche cut out in the side of the shaft.

The pump is provided with two clacks, the *suction-valve* (*bottom-clack*), which opens when the plunger makes its upstroke, and allows water to enter the working pump (*plunger-case*), and the *delivery-valve* (*top-clack*), which opens when the plunger begins to descend, and the bottom-clack closes from its own weight. Each of the valves is seated in a chamber (*H-piece* and *door-piece*) provided with a door, having the same object as the single door-piece of the lift-pump; viz., for inspecting and changing the valves.

The plunger is a hollow cylinder of cast iron or brass, turned outside; it is filled up with a rod of timber, or else the bottom is closed by a cover traversed by a metal rod attached to the wooden one.

The column of pumps, or rising-main, is erected vertically, and its weight is sustained by the same bearers that carry the pump. It is bent, however, at the top, so as to avoid the bearers of the next lift, and enable it to discharge into the cistern.

An important question that has to be considered is the distance apart at which the lifts should be fixed, or, in other words, the height to be given to each column.

Theoretically, as we have already stated, this height is *arbitrary*. The greater the number of the lifts, the greater is the cost of putting in the pitwork; and at the same time we increase the number of parts which entail friction and require repairs; besides which there will be a greater chance of having an accidental diminution in the delivery from one of the lifts being out of order.

On the other hand, we may fairly say that though the rubbing parts, such as the plungers, are fewer in number with very long lifts, yet they have individually to sustain a greater pressure, because the gland must be tightened in proportion to the pressure in the plunger case; and though there are *fewer parts* to be kept in order they *are more heavily loaded*, and are *less easily kept in good condition*, and require more frequent repairs. With regard, then, to friction and repairs, there might be a sort of compensation, and long lifts would still retain the advantage of being less costly to put in. But there is another aspect of the question which causes this advantage to disappear. It is this: In proportion as the height of the lift becomes greater the strain in all the parts of the pump, for a given speed of working, increases considerably in consequence of the inertia of the column of water. This column, which is at first in a state of rest, has to acquire the same velocity as the plunger. When the plunger begins its downstroke it receives a shock, which is felt also by the working pump, by all the parts of the valve-chamber, and at the base of the rising-main. The shock is all the more trying, because at the end of the stroke the same inertia tends to make the column of water

continue its upward course, even after the plunger has stopped, and thereby the pressure is considerably reduced, and rendered *nil*, or even *negative*, if towards the end of its course the plunger has received a *retardation* greater than the acceleration due to gravity.

We may conclude from this that the speed of working should be reduced as the lifts are fixed further apart; consequently, *for a given amount of water to be pumped*, an increase in the number of lifts enables us to work with a greater number of strokes per minute, and so to use a smaller engine and smaller pumps. This is a compensation for the cost of putting in a greater number of lifts when we are driven to it from having to use parts of nearly as large dimensions as are sanctioned by practice.

In practice, lifts are rarely found less than 50 yards high, and those of 100 yards are exceptionally great. As a rule, a mean height is adopted of 60 to 70 yards.

Figure 425 represents the ordinary type of plunger-pumps. Figure 426 shows in addition how the cistern is arranged.

It will be noticed that the arrangement of the plunger-case is not the same in the two figures. In the former there is very little play between the plunger and the case in order to reduce the residual space which may become filled with air during the suction, either through the suction-pipe, or through the packing, if it is not tight. In the latter figure there is no residual space; but it is necessary to make the plunger-case very much larger than the plunger, so that the water may not meet with too great a resistance during the downstroke as it passes from the plunger-case into the column. Figure 426 shows also how the top and bottom clacks are connected, so that there may be no tendency in any case, during the up or downstroke, to displace them from their seats.

(538) *The column of pumps, or rising-main.*—The column of pumps, whether for lifting or forcing, is usually made up of cast iron pipes joined together.

It might be supposed that miners would employ some of the joints used in other branches of engineering; but in mining we have special conditions arising from the fact that the column is exposed to slight movements of the bearers, or of the sides of the

shaft; and that it is necessary to be able to repair the joints, or replace a damaged pump with ease and speed.

We must, therefore, avoid both *rigid joints*, such as rust joints, and *faucet joints*, because they do not admit of a pipe being taken out or put in without shifting the neighbouring ones.

It is better to make the joints by having two flanges brought together by bolts, with some compressible substance between them to ensure stanchness. Each flange has a projection, which is planed down, and then one or two circular grooves are turned out in its face, and the grooves in any two flanges made to correspond exactly to each other. The joint is made by putting a flat iron ring wrapped round with tarred hemp (*engine-shag* or *bal-shag*, a coarse, flannel, is used in Cornwall) between the two flanges, and then tightening up the bolts as far as possible.

In a long column of pumps we should take into account the difference of the strain at the different points, and make the lowest pumps the thickest. We may, therefore, have pumps of two or three different thicknesses in the total height of the column.

If the water of a mine is acid, the principal parts of the pumps, such as the working barrel, bucket, and valves, should be made of gun metal, or, at all events, bushed with it; but we should not think of making the rising main of this material on account of the extra cost. All we need do is to paint the inside of the pumps before fixing them, and put in a thin wooden lining to preserve the coat of paint.

The lining consists of a number of staves cut out of plank, about $\frac{3}{8}$ inch (1 centimetre) thick, which are kept in position temporarily, and finally tightened up by driving in the last two staves, made wedge-shape, one against the other, like gib and key.

The effect of this lining is not so much to hinder the water from *touching* the pumps as to prevent *the current* from acting on the sides, peeling off the paint, and so readily attacking the iron. It reduces the area of the pipe but very slightly.

(539) *The main-rod and the secondary rods.*—The main-rod of a pump is usually made of timber, either oak, if it can be had, or more frequently pine from the North of Europe.

Towards the bottom the rod is formed of a single balk, but very often two balks fixed side by side are used near the top. The ends of the balks may be united by a scarf-joint; but more frequently they are simply butted together, as this prevents the timber from being cut into, and so possibly weakened. The joint is made by long bands of flat iron, called *strapping-plates*, fastened to each rod by bolts passing through them from side to side; the bolts are arranged in two lines, so as not to cut the same fibres of the wood too often. (Fig. 427.)

Instead of strapping-plates two pieces of timber acting as large cleats may be used; they are kept tight against the rod by staples and glands. The joint is completed by a series of wooden pins, half in the rod and half in the cleat.

This system, which is shown in figure 428, dispenses with bolts, and seems to us to be preferable to the former. Care must be taken in planning a joint not to let it be a *weak point*. It is, therefore, necessary that the sum of the sections of the two cleats should be at least equal to the section of the rod at this point, and the same should hold good with the sum of the longitudinal sections of the pins. Under these circumstances there will not be a greater tendency for the joint to give way, either from a breakage of the cleats or pins, than for the rod itself to break near the joint.

This condition of being quite as able to resist any breaking strain as the rod itself, is, after all, an essential point in any longitudinal joint; and it is with reference to this that we should determine the section of the strapping-plates and bolts just described in the first mode of jointing.

The secondary rods for drawing-lifts, or *bucket-rods*, are attached to the main-rod by means of an iron *set-off*, the rod being fastened to the *nipple* of the set-off as shown in figure 429.

The bucket-rods are made of iron, or sometimes of wood, although wooden rods have the inconvenience of taking up much more room in the column, and causing much more friction during the downstroke.

When we have, not a series of drawing-lifts, but simply the bottom lift, there is no necessity for placing the bucket-rod on one side, it is then simply a prolongation of the main-rod.

In the case of the force-pumps, the secondary rods, or plunger-rods, are attached to the main-rod by set-offs, consisting of pieces of balk, which fill up the space between the axes of the two rods. (Fig. 430.)

We have already remarked that occasionally the plunger-rods, and bucket-rod are all arranged in a line with the axis of the main-rod. This system has the double advantage of requiring less space in the shaft, and of concentrating in one line all the forces acting on the rod. For this purpose the rod is broken off at each lift. Set-offs are fixed on each side at each end, and these are connected by two long pieces of balk, or by rods, or plates of iron. The whole forms a sort of mortise enclosing the bearers and the working pump of the lift, with an amount of play at least equal to the stroke of the rods. This arrangement is shown in figure 431. The connecting-balks might be replaced by iron plates with advantage if there happened to be little room in the shaft.

Main-rods have also been made of iron; they were introduced more than thirty years ago, but up to the present time they have come very little into use. This is not due to the fact that there is a difficulty in constructing a long iron rod, which has to work simply by traction, or can, at all events, be so arranged as to work only in that manner.

Iron offers the advantage of greater durability, especially in an upcast shaft, where the hot and vitiated air injures timber very rapidly; but when the smoothness of working is taken into consideration wooden rods seem preferable.

There is also this advantage with wooden rods, that with a given speed of working the whole mass is set in motion at the commencement of the *indoor* stroke in a less sudden manner, and that consequently the joints suffer less than when the rod is too rigid. It appears to us that the advisability of using wooden rods increases with the depth of the shafts, and the speed of working the engine.

Main-rods have not only been made of iron, but also of steel; such rods, and especially steel rods, are lighter than wooden ones. The iron or steel rods should be designed of such a shape that any given section capable of supporting the necessary tension should

present a maximum amount of resistance to flexion. Consequently they are either made with a central core and four wings, or else in the form of a *hollow tube*, either square or circular in section. (Fig. 432 A, B.) By riveting on set-offs and long strapping-plates, it is very easy to divide the rod in two at each lift.

The rod may also be constructed in the form of a lattice-girder, made of two plates of flat-iron braced by a third one, bent in zig-zag fashion, and firmly riveted to each between them. (Fig. 433.)

All this is familiar to engineers, and can be accomplished without the slightest difficulty. However, the lightness of the rods is not usually a point to be desired, because we are often led, on the contrary, to give them additional weight.

We may fairly conclude that this is one of those cases, more frequent in practice than we think, in which the word *modification* need not necessarily signify *improvement*, and that metallic rods have no decided superiority over wooden ones.

(540) *Balancing the rods.*—The main-rod is frequently, indeed in the case of large pumps one might say generally, very much heavier than the column of water to be raised. All the excess of weight of the rod above that of the column of water, plus the friction, should be balanced, save a little surplus, which is left to make the out-door stroke begin distinctly.

It will even happen that the main-rod is overweighted on purpose, but at the same time balanced, in order to increase the mass set in motion. The object of this is to produce a *moderate acceleration* only at the commencement of the *indoor* stroke, when the steam has its full pressure, and the power is *very much greater* than the load; for it is on the rate of this acceleration that the reactions of the force of inertia which are set up in the various parts depend, and these reactions again increase the strain on the entire system.

A counterpoise acts by means of a beam. This is either a balk of timber suitably strengthened, like the beams of the first Newcomen engines (fig. 434), or else it is made of cast iron, either in a single piece, or in two cheeks; or, better still, it is made of sheet iron and angle iron, like the ordinary beam of a Watt's engine.

One end of the beam is attached to the main-rod either by a chain, or better still, by long iron rods jointed at their extremities, and the other end is weighted as much as is thought necessary. A large box, made of wood or sheet iron, is fixed to its free end, and filled with stones or lumps of iron; or sometimes pieces of iron having holes in them are strung on to a tail-piece at the same point.

Hydraulic balances are also used; they are arranged exactly like ordinary plunger-lifts, save that there are no valves. The plunger of the balance has a reciprocating motion like that of the rod, and receives the constant pressure *from below upwards* of a column of water, which has the area of the bottom of the plunger for its base, and the difference of level between the bottom of the plunger and the top of the column for its height. The effective weight of the main-rod is reduced by this amount, just as it would be if an equivalent counterpoise acted on it by means of a beam.

The system of hydraulic balances is specially adapted for single-acting water-pressure engines. All that is necessary is to fix the engine below the adit level, as was done at Huelgoat. The effective height is increased by so much during the upstroke of the piston; but the water forced by the same piston to the level of the adit acts as a brake, the resistance of which compensates exactly during the downstroke for the excess of motive-power developed during the upstroke. It is an hydraulic brake where one piston acts for both brake and motive-power.

We should also mention, as one of the functions of M. Bochkoltz's regenerator, that it acts as a counterpoise having the special characteristic of increasing in energy as the end of the stroke is approached.

The same property is possessed by M. Guary's *compressed air balance*, which differs from the hydraulic balance, inasmuch as the plunger forces the water into a chamber where the air is compressed, instead of forcing it up a column of pipes. This apparatus certainly enables us to increase the speed of the down, or *out-door*, stroke, all other things being equal. To make it complete there ought to be a little feed-pump forcing a little air into the reservoir at each stroke to make up for leakages.

(541) *Bearers and guides.*—Each plunger-lift is sustained by a fixed support, generally made of several large balks of timber placed one above the other, and resting in deep *hitches* cut in the sides of the shaft. If the shaft is very wide they can be supported in the centre by inclined struts, or *spur-pieces, footed* in the sides of the shaft.

The bearers ought to be put in very firmly, because they are subjected to a considerable pressure, which includes *first of all* the total weight of the pump, and the rising-main with the water in it; and *secondly,* during the downstroke of the rod, the weight of a column of water having the end of the plunger for its base, and for its height that of the lift. The bearers have also to carry part of the weight of the cistern, and should have a platform, or *sollar,* fixed upon them, for enabling the pumps to be examined with ease.

The same reasons which have led to the use of iron in the place of wood for main-rods may induce us to employ the same material for bearers. They would then be formed of a sheet iron girder, with one or two cheeks, stiffened by angle iron, like the girders of an iron bridge, and all the dimensions can readily be ascertained by calculation.

The guides, or *stays,* are formed of two balks of timber, parallel to the bearers, between which the rod moves with very little play. If thought proper, the wear on the sides of the rod and guides can be prevented by fixing thin boards (*lining-boards*) on all the rubbing surfaces, which are changed as often as it is found necessary.

The mere effort of keeping the main-rod in a vertical position, and preventing vibrations, does not cause any great strain on the guides; but this is not the sole purpose for which some of the cross-beams at least are put in. They may also be required to support the pipes forming the rising-main by clasping them under the flange.

Cross-beams are required finally to act as catches in case the rod should break accidentally. It will generally be during the up-stroke that a breakage will occur. The lower part will fall in consequence of its own weight, and the upper part will be jerked up suddenly

by the pressure of the steam. According to the position of the fracture, any one of the catches may be required to act either to check a fall or stop an upward motion. It is, therefore, necessary to put them in firmly enough to be able to resist both kinds of shocks. *Wings* are fixed on the rod above and below the catches, and closely approach their upper and lower faces alternately. The wings are made of balks of timber fastened on to the rod by iron staples and glands, as shown in figure 428. Lastly, in order to deaden a blow from the wings, the top and bottom faces of the guides are provided with an elastic cushion, which may be arranged in various ways. For instance, a series of thin boards, separated by wooden pegs, might be piled up. The successive crushing of these boards and pegs, in the case of an accidental breakage, seems well calculated to deaden the *vis viva* of the mass striking the blow.

(542) *Various accessory arrangements.*—We include under this head the arrangements made to facilitate the erection of pumps and their repairs, to start them, and drive out the air, and to ascertain the state of any parts that are not visible.

With reference to these arrangements we may make the following remarks:

1. The pumping compartment ought, as a rule, to be large enough to receive a *ladder-road*, and there must be a platform, or *sollar*, at each lift, without taking into account the intermediate sollars, which may be necessary in order to make the ladder-way safe, and easy for climbing. A little above the door-piece of each lift arrangements should be made for fixing pulley-blocks, by means of which the doors of the valve-chest and H-piece can be lifted off as well as the valves when they require repairs.

2. A capstan, worked by hand or steam, is erected near the top of the shaft for the purpose of lowering the pumps. It is usually retained after the pumps are fixed, so as to be available for lifting any heavy weights during repairs, and for changing any large parts of the pitwork. Figure 435 represents a steam-capstan, which can be as easily handled as a winding-engine, as it is provided with two cylinders.

3. If the pumps were started while empty they would work in an irregular manner, which it is advisable to avoid. It is best to charge the pumps by pouring water into the top of the rising-main. In order to ensure the pumps working properly from the very first stroke, we may also fill the H-piece, and even the windbore. In this case the windbore should be closed at the bottom by a retaining-valve, and the rising-main should be put in communication with the H-piece and windbore by means of a small pipe furnished with cocks. These two vessels can then be filled with the water poured into the rising-main. If the little pipe is provided with branches corresponding to the H-piece and windbore, we are enabled at any moment to ascertain the state of the bucket and clacks, by observing with what force the jet of water escapes from one of the branches on opening the cock which commands it.

(543) The details given in Nos. 537 to 542 refer to pumps permanently fixed in a shaft, which is partially or exclusively devoted to them.

It is also necessary to consider another case, which sometimes requires more powerful means of drainage, but under very different conditions from those we have assumed above. This case presents itself in combating water while sinking a shaft by the ordinary methods through more or less water-bearing strata.

Fixing pumps in a work of this kind is attended with certain inconveniences, which are mainly due to the fact that the pumps must be lowered gradually as the shaft is deepened, that they require frequent repairs in consequence of the water being muddy; and lastly, that they are often completely submerged if the engine is stopped even for a short time.

This *sinking-lift*, or at all events the windbore, ought to be so suspended that it can be always lowered, as the shaft is deepened, into the little *sink* or *sump*, that the *shaftmen* or *sinkers* always make for the purpose of collecting the water.

As the bucket-rod cannot be lengthened in each case to exactly the same amount as the lift has been lowered, the working barrel is made just as much longer than the stroke as the shortest lengthening piece that can be added to the bucket-rod. The great length of

the working barrel generally renders it advisable to make it in two pieces; and these are united accurately by a carefully-planed joint, which is tightened by keys driven through lugs. The projecting band, formed outside the working barrel by this joint, serves to catch the collar by which the lift is suspended.

Although it is undoubtedly an advantage to reduce the weight of the lift, the working barrel should be pretty thick, because it may have to be rebored several times while sinking through the water-bearing measures. The same remark applies to the windbore, which must be made capable of resisting the effect of blasting. The windbore is sometimes connected to the working barrel by a flexible and extensible joint, so that the bottom end can be moved about to the different parts of the shaft where the *sink* may happen to be cut out. In other cases the joint is rigid, and the end of the windbore rests on the bottom of the sink.

In order to diminish the weight that has to be supported, the column of pumps may be made of sheet iron instead of cast iron.

Wrought iron pipes, like cast iron ones, are joined by properly-adjusted flanges, which are made by bending a piece of angle-iron while hot into a hoop, and welding the ends together.

As soon as the engine stops the pumps become submerged, if not regularly, at all events frequently, and, consequently, it is necessary that they should be lift-pumps with a bucket. They should be made in such a way that both the bucket and the clack can easily be drawn up through the column; the valve merely *rests upon its seat.* The valve-chamber is useless; for it is a simpler and speedier operation to draw up the valve after having pulled out the bucket, than to open the door of the valve-chest, which it might not be possible to close again in time if the water happened to rise very rapidly. The pump would then be rendered useless.

(544) As lift-pumps act during the upstroke, the steam has to raise both the rods and the column of water; the rods then re-descend by their own weight. On the other hand, we are generally obliged to work the engine at its maximum speed, because the first consideration after an accident, which has allowed the water to rise

to a certain height, is to make all haste to pump it out, and enable the sinkers (*shaftmen*, Cornwall) to get to the bottom of the pit again with the least possible loss of time.

This condition excludes the use of expansion, and the employment of a cataract, which leaves an interval of absolute repose between two successive strokes. Endeavours are also made to simplify the machine as much as possible, and by omitting all complicated parts to lessen the chance of the pumps getting out of order. This chance is far too great already, owing to the quick stroke, and the muddiness of the water to be raised; in fact, the water may even carry coarse sand in suspension, which rapidly wears out the leather gearings, especially if it is of a siliceous nature.

The ordinary type of engine adopted for sinking through watery strata is a high-pressure Bull engine, with no expansion to speak of, and without a condenser or cataract. It is with engines of this kind that pits have been sunk during the last few years in the departments of the Pas de Calais and the Moselle, before Chaudron's system was so extensively adopted; and some pits are still being sunk with them at the present time.

The steam cylinder is usually placed directly over the shaft. It is supported by strong bearers, made of wood or sheet iron, and resting on two thick walls of masonry, between which lies the top of the shaft. These walls are built up sufficiently high to render it easy to conduct all necessary working operations without being inconvenienced by them.

M. Vuillemin, in some instances, has replaced the vertical cylinder by a horizontal one. The piston-rod then works the main-rod by means of a chain passing over a return pulley.

This arrangement renders the mouth of the shaft more free and unobstructed, and it may even have to be adopted by necessity if the ground near the top of the pit is unstable; indeed, the engine can be put back as far as is thought proper, provided that the chain is made long enough.

A steam-engine worked on this principle is essentially *disadvantageous* with reference to the consumption of fuel; and if the condition of a rapid stroke prevents much expansion being used, it

seems to us that it is almost *necessary* to employ condensation, even if that entailed the erection of a special condensing engine, for fear of making the principal engine too complicated. The adoption of condensation is warranted, not only by the general economy in working a high-pressure engine which may be expected from adding a condenser, but also from motives depending on the special conditions of work of the machine about which we are now concerned. The engine, in fact, is erected from the beginning with a cylinder of sufficient diameter to work pumps of a given size down to the depth at which the water-bearing beds are expected to be met with (60, 80, 100, 150 yards, or more). For instance, it is desired that the engine shall be able to work the pumps at a depth of 150 yards with steam at an effective pressure of six atmospheres; if this be so the engine will only admit of an effective pressure of three atmospheres at 75 yards, one atmosphere at 25 yards, and so on in proportion; in other words, it will be necessary to reduce the pressure of steam in the boilers very considerably, or to throttle the steam a great deal, as long as the shaft is shallow relatively to its intended depth.

The expenditure of coal at first will be that of a non-condensing engine, working, not at high pressure, but at a pressure increasing with the depth, and *scarcely* exceeding that of the atmosphere at the beginning. Now we know what amount of work per pound of coal would be obtained from one of Watt's low-pressure engines worked without a condenser.

Thus, if we suppose that the machine has been put up to work, as we have just said, at a maximum pressure of six effective atmospheres without condensation, the economy of fuel obtainable by adding a condenser would be, not $\frac{1}{8}$, but a *far greater proportion*, approximately $\frac{3}{8}$ at a depth of 25 yards, and even one-half at 75 yards, and so on.

This point seems to us to be of the utmost importance, when we reflect upon the large sums expended in coal for sinking through watery strata. Instances might be cited where the cost of coal alone has reached, and even exceeded, £110 per yard sunk (3000 francs per metre), and if a considerable saving can be effected on such a sum it certainly should not be neglected.

(545) Another important improvement which has been introduced consists in *greatly* increasing the size of the pumps for watery strata, so as to diminish the number in use at one time for raising a given quantity of water. By so doing the shaft is much less blocked up, and what is no less important, the number of pistons and valves to be kept in order is diminished.

This last point is not without importance, because when the limits of the pumping-power at our disposal have been nearly reached, the least stoppage for changing a bucket or clack allows the water to rise, and it may happen that many hours of hard pumping will be required to lower it again sufficiently for the men to resume work at the bottom of the shaft.

In this way we sometimes get into this strange predicament, that the duration of the gearing does not exceed the time requisite for lowering the water which rises while the bucket and clack are being changed; so that all the time is spent either in changing the bucket and clack, or in pumping out the pit again, and consequently none remains for the work of sinking. In a case of this kind the cost mounts up beyond all anticipations, even without allowing for the material difficulties which naturally follow in weak ground, if the pumping has to be carried on for an unlimited period.

The use of sheet iron pipes has enabled us to increase the diameter of the pumps without rendering their weight immoderate.

Thirty or forty years ago the largest pumps used for sinking through watery strata were only 14 inches ($0^m{\cdot}35$) in diameter. Since that time pumps have been made in sheet iron of 20 inches ($0^m{\cdot}50$), and even 27½ inches ($0^m{\cdot}70$). A single pump of this size is equal to four of the old ones, and the advantage of using it is evident. If two are required they can easily be fixed in the pit, whilst it would be impossible to put in the eight which they replace.

(546) When a pit has to be sunk to some depth through watery strata, say for more than 55 yards (50 metres), it is advisable to have two lifts, as in ordinary pumping, and so diminish the weight of the sinking-lift, and the load on its bucket. For this purpose

a cistern is fixed at about one-third or one-half of the presumed height of the watery strata, and receives the discharge of the sinking-lift, which is then pumped up by a fixed-lift resting on the bottom of the cistern. This must be fixed very firmly, and its weight should be sustained by the tubbing. In order to effect this object it is made to rest on the butt ends of a series of beams strongly fastened by nails, or wood screws, to several consecutive rings of tubbing.

We also endeavour to manage with only one cistern, or, in other words, to clear the total thickness of the watery strata with two lifts. It is difficult, however, to make lifts act well for more than 65 yards (60 metres) on account of the very rapid wear of the gearing; consequently, if a shaft has to be sunk through watery beds for 130 yards (120 metres) or more—and this is always known beforehand—it is better to divide the height into three nearly equal parts, and to fix two cisterns and two lifts, in spite of their blocking up the shaft to some extent.

The rods of all the pumps, whether fixed or hanging, are fastened either to the main-rod, or directly to the piston-rod of the steam-engine, by means of a strong cast iron coupling-plate keyed on to it. The various rods are hung from the circumference of this plate. This last arrangement is the most convenient as long as there is only one cistern, because all the connections are kept at the surface, and any one of the buckets can thus be drawn out more easily and rapidly.

A hand or steam-capstan, or else a horse-whim, should be put up at the mouth of the pit for carrying on these operations, which are of daily occurrence, and should be quite independent of the drawing machinery required for the sinking, which works in a separate compartment of the shaft.

We must bear in mind that a work of this kind causes a very heavy *daily* expenditure in coal; besides which it is an extremely slow process, especially in quartzose rocks, where, as we have already pointed out, the grit suspended in the water wears out the buckets and clacks with extreme rapidity.

It may happen in a case of this kind, that the time required for pumping out, or *forking*, the water that rises whilst a bucket and

clack are being changed is nearly equal to the duration of the gearing. We then find ourselves in the situation mentioned in the preceding paragraph; and weeks, or even months, may elapse without any progress being made. Indeed there are instances of its having been necessary to abandon works of this kind after they had swallowed up thousands of pounds.

It seems to us that, at the present day, this process of sinking through watery strata ought to be looked upon as obsolete; and we are of opinion that where there is a reasonable presumption that the amount of water will be very great, it is advisable, as a rule, to give it up, and adopt one of the new processes described in chap. ix., and especially that of M. Chaudron.

Figures 436 to 439 represent the principal arrangements for pumping in watery strata, mentioned in Nos. 543 to 546; and their various details are described in the Explanation of the Plates.

(547) We will now add a few numerical data concerning the machinery described above. (Nos. 537 to 546.)

The pumps are rarely less than 8 inches in diameter, and often 14. The latter diameter corresponds to 20 gallons delivered per 3 ft. of stroke (1 hectolitre per metre). A diameter of 20 inches ($0^{m}\cdot50$) constitutes a good-sized pump; however, fixed pumps have been made with diameters reaching up to 3 feet 3 inches (1 metre).

The length of stroke varies from 4 feet 3 inches ($1^{m}\cdot30$) for pumps worked by cranks, to 8 feet, 10 feet, or even 13 feet ($2^{m}\cdot50$, 3 metres, 4 metres), for the largest engines working with direct traction.

The number of strokes per minute may be greater for rotary engines than for those working by direct traction; for engines worked without expansion, or with Woolf's system of expansion, than for those with a high rate of expansion in a single cylinder; for a large number of lifts than for a small number, and lastly for those provided with a Bochkoltz regenerator than for those without it. The number of strokes per minute of a given engine may also vary within certain limits, without any other inconvenience than the wear of the parts, which increases rapidly as the speed is quickened.

With draining machinery of the largest dimensions, including pumps of 3 feet 3 inches (1 metre) diameter, and 10 feet (3 metres) stroke, a very suitable speed will be 3 to 4 strokes per minute. With 4 strokes the delivery will be more than 2,000 gallons (9 cubic metres) per minute. If the pumping is carried on from a depth of 550 yards (500 metres) it is evident that the theoretical work of the engine exceeds 1,000 horse-power.

In exceptional cases of necessity, when the water is very quick, such a set of pumps might be worked at 5, and perhaps even 6 strokes per minute, provided a regenerator were added; the power expended would then become 1,500 horse-power.

A smaller engine may very well be set to work at 5 or 6 double strokes per minute, and may be pushed to 7, or even a little beyond that. The speed of a large engine, for sinking through watery strata, may be 10 strokes a minute, or even 12 in exceptional cases; but with this latter speed the vibration becomes considerable, and all the parts of the machinery suffer greatly.

The maximum velocity during the upstroke may reach 5 feet to 6 feet 9 inches ($1^{m}\cdot50$ to $1^{m}\cdot75$) per second, and it ought not greatly to exceed 3 feet 3 inches (1 metre) during the downstroke, when the water is being forced up.

The height of the drawing-lift may be fixed in round numbers at 20 yards (20 metres), and that of the plunger-lifts at 65 yards (60 metres). [See Nos. 536 and 537.]

When a pump is in good order the actual delivery is practically equal to the theoretical delivery, calculated from the diameter and stroke of the plunger. It may even happen, in a manner easily understood, that owing to the effect of inertia the delivery may be *slightly greater* in pumps worked with a rapid stroke.

In practice we must reckon on a loss of $\frac{1}{10}$, so as to make ample allowance in case the packing should not be in good order.

It may be calculated that, if the engine is erected under favourable conditions, we shall obtain, *in water raised*, 50 per cent. of the theoretical work of the motor in the case of rotary machinery and simple means of transmission, and 70 to 75 per cent. with direct-traction engines properly regulated. It is generally allowed that the useful weight of the main-rod ought to exceed by $\frac{1}{10}$ to $\frac{1}{8}$

the weight necessary for raising the delivery-valves of the plunger-pumps.

The above data afford us the necessary elements for getting out the design of pumping machinery, and an estimate of its cost. The strength of the parts may easily be calculated from the strains they are subjected to, and knowing the necessary strength it is easy to deduce the cost from the prices current at the time and place.

In making the calculation we should assume that the engine will work *slowly* and during *a limited number of hours* per day, eight hours for instance; this leaves us ample means of facing any subsequent increase in the water by augmenting the speed and duration of the working. By making the engine work half as fast again, and keeping it at work for sixteen hours out of the twenty-four, which is quite possible, we can cope with an influx of water three times as great.

(**548**) The cost of erecting pumping machinery consists of the price of the engine, which depends principally on the amount of power required, and the price of the pumps and all their appendages, which increases with their size, and especially with the depth of the pit. It is impossible, therefore, to lay down any price with reference to the motive-power only.

We will simply quote, as an example, the cost mentioned by M. Luyton of pumping machinery erected in a shaft 153 yards (140 metres) deep, in a mine of the department of the Loire.

The engine works by direct traction. The diameter of the cylinder is 4 feet 11 inches ($1^{m}\cdot50$), and the stroke 9 feet 10 inches (3 metres). It works two plunger-lifts, and one drawing-lift of 14 inches ($0^{m}\cdot35$) in diameter, making 3 strokes per minute, and it might very well, without the slightest inconvenience, make 6.

The cost of erection in round numbers was as follows:

A. For the Engine.

	£	Francs.
Engine-house	452	11,300
Five boilers with their furnaces	1,224	30,600
Chimney	80	2,000
Engine, pipes, and sundries	1,580	39,500
Total	3,336	83,400

B. For the Pumps.

			£	Francs.
Rising-main			616	15,400
Pumps, properly so-called, ready to be fixed—				
Cast iron		392	472	11,800
Gun metal		80		
Main-rod—				
Timber		208	892	22,300
Ironwork		496		
Balance-bob		188		
Repairs to shaft, putting in bearers, and fixing the pumps			544	13,600
Carriage, and sundries			140	3,500
Total			2,664	66,600

Say for the total cost, including erection, £6,000 (150,000 francs). This makes the cost per current *yard*—

	£	s.	d.	
For the engine	21	16	0	(596 francs per metre)
For the pumps	17	8	0	(476 „ „)
Total	39	4	0	(1,072 „ „)

In round numbers we may put the cost at £39 per yard (1,000 francs per metre).

In very deep mines, with very large pitwork, the first of these figures would probably be somewhat smaller, the second somewhat larger.

(549) Just as in the case of giving an estimate for putting in pumping machinery, it is impossible to state any average for the cost of pumping, whether referred to the quantity of water raised, or to the amount of horse-power required for the work. The cost of pumping varies within larger limits even than the cost of winding; the reason of this is that the expenditure in coal is one of the principal items, and that this varies extremely for a given amount of power, according to the perfection of the engine, and the price of coal in the district.

All that can be said is that the *cost of raising a ton of water by the winding-engine* may generally be taken as less than the *cost of*

raising a ton of mineral, because there is less labour, and because the consumption of coal is less, inasmuch as the steam produced can be better utilized since the engine is worked in a more continuous manner.

Thus, we might make a reduction of about one-half on the labour, and if we adopt the estimate given in No. 468 of 2½d. (0·25 franc), for raising one ton from a depth of 437 yards (400 metres), we should put the cost of labour at 0·365d.; in the cost of coal we might take off about one-fifth, say 0·134d. (0·0134 franc), or altogether about ½d. (0·05 franc), and therefore the cost of raising a ton of water, under the circumstances referred to, would be reduced from 2½d. to 2d. (0·25 franc to 0·20 franc).

We may assume that, by substituting a Cornish engine for the winding-engine, the cost of labour will be reduced slightly, and the consumption of coal very considerably, and that the expense of keeping engine and pumps in order will not be greater, and perhaps rather less, than would be requisite for a winding-engine and ropes. The total net cost would probably not exceed 1¼d. (12 centimes).

In other words, the cost of raising one ton of water a hundred yards (one metric ton a hundred metres), where 600 tons are raised daily from a depth of 400 yards (400 metres), will be ½d. (0·05 franc) by water barrels, and ¼d. (0·03 franc) by pumps.

We must recollect that we have assumed conditions *very favourable* for the use of water-tanks, inasmuch as the winding-engine is supposed to be kept in constant work.

If the quantity of water to be raised were very much greater, water-barrels would no longer suffice, and if it were less the expense would increase more rapidly with the water-barrels than with the pumps.

The cost of ½d. (0·05 franc) might almost be considered as a *maximum*, whilst that of ¼d. (0·03 franc) without being a *minimum*, might possibly be reduced under certain favourable circumstances. For instance, the depth of the pit might be somewhat greater without its being necessary to increase the number of lifts, all other things except the length of the rising-mains remaining the same. There would be about the same expense in keeping the pumps in order, exactly the same amount of labour, and the cost

of coal would be the only item increasing in proportion to the depth.

When we reflect upon the moderate figure ¼d. (0·03 franc) that we have just laid down, and the facts that, on the one hand, the quantity of water to be raised from a mine with a given extent of horizontal development increases but little with the depth, and that, on the other hand, the system of lifts worked by a main-rod can be extended to any depths we please, like a man-engine, we are led to the conclusion that if at some future day the working of mines will be limited in depth by some natural circumstance, this is not likely to be owing to the material difficulty or expense of raising the water.

With regard to its capability of being applied to greater depths, the pumping machinery now in use has *the same elasticity,* so to say, as the man-engine, and *a greater elasticity* than the machinery used in winding.

CHAPTER XX.

ON THE VENTILATION AND LIGHTING OF MINES.

(**550**) The air of mines, like that in every confined space, undergoes two kinds of alteration; on the one hand, by the withdrawal of part of its oxygen, and on the other, by the admixture of foreign gases.

The withdrawal of oxygen is principally due to the respiration of men and animals, and to the burning of lamps.

These two phenomena are, to all intents and purposes, the same in kind, the act of respiration being neither more nor less than a true combustion which takes place in the lungs, and the products being in both cases almost exclusively water and carbonic acid.

It is generally admitted that the quantity of air inhaled by a man at rest is about 0·42 to 0·45 cubic foot (12 to 13 litres) per minute, 600 to 670 cubic feet (17 to 19 cubic metres) per 24 hours. This quantity is increased two or three-fold, or even more, during digestion, or where the man performs rapid movements, or undertakes any kind of muscular exertion. The inspired air does not contain more than a few ten-thousandth parts of carbonic acid; but, on the other hand, the expired air contains from 3 to 4 per cent. of the same gas, and the free oxygen is reduced in proportion. Air containing this proportion of carbonic acid already produces a difficulty in breathing, and when it contains 10 per cent. it causes asphyxia. The volume of 600 to 670 cubic feet is, therefore, the least quantity of fresh air that ought to be supplied per 24 hours to a confined space for each man who remains in it. This quantity ought to be trebled if the men are at work. A lamp, again, may be set down as equal to a man, and a horse as equal to three men.

A further withdrawal of oxygen is caused by various chemical actions which take place in a more or less invisible manner; these generally consist in the slow oxidation of various mineral or organic substances which have not reached their highest stage of oxidation, and are consequently still more or less combustible.

Thus, for example, iron pyrites effloresces into sulphate of iron; certain proto-carbonates, notably the proto-carbonate of iron, are changed into the peroxide of the metal, &c.

A similar effect is produced with certain kinds of coal, which tend to become hot in the presence of air, and may even become incandescent, when the coal is liable to spontaneous combustion.

This phenomenon of heating takes place either in the heaps of small coal stored on the surface, or in the coal which is left behind in the waste during the process of removing pillars, or, lastly, even in pillars themselves, which have been left standing for a long time before being worked off, and have become more or less crushed and fissured.

In all these cases, the coal which becomes hot or takes fire must be looked upon as a porous mass, into which the air can penetrate, but cannot renew itself save with very great difficulty and slowness. The mass becomes a worse conductor of heat than in its natural condition on account of its increased porosity, and may be supposed also to exercise a kind of condensing action on the molecules of oxygen more or less similar to that produced by spongy platinum. This condensation gives rise to heat, and facilitates the combination of the oxygen either with the molecules of carbon itself, or more probably with those of the various hydrocarbons, such as light carburetted hydrogen, which have a tendency to be disengaged from the mass, and are, as it were, in a nascent state.

This heating or spontaneous combustion of small or broken coal is very often attributed to the oxidation of pyrites. This may be true to a certain extent in the case of coals which contain a large proportion of pyrites, but it is equally certain that the same kind of accidents take place with coal which contains no pyrites at all, or only an insignificant quantity.

Lastly, a similar process of combustion takes place, in a general way, with all the organic substances which are left behind in the

workings; they undergo a kind of fermentation, and at length disappear altogether, having resolved themselves into various gaseous compounds, in which a greater or less quantity of oxygen exists in the state of combination.

(551) The foreign matters which are mixed with the air consist principally of those which are produced by the various chemical actions referred to above; that is to say, watery vapour and carbonic acid, in the case of complete combustion; then carbonic oxide, nitrogen, ammonia, hydrocarbons, sulphuretted hydrogen, and finally, various complex compounds possessing more or less smell, and known by the name of miasmata, &c. &c., which are produced by an incomplete oxidation, or even without the intervention of oxygen at all.

To this list must be added the substances which result from certain special chemical actions, such as that of acid waters upon carbonates; secondly, the gases and smoke produced by the explosion of blasting-powder; thirdly, the impalpable dust which is raised and kept in suspension by the action of shots, by all the rapid movements to which the minerals are subjected during their transit from the working places to the shaft, and lastly, by any circumstances which may produce more or less violent currents in the air of the mine.

This dust may in some instances be injurious to health, as, for example, in mines in which mercury and arsenic are obtained, where it exercises the poisonous influence belonging to it. Even in coal mines, although the dust may not produce chemical actions, it has a physical or mechanical effect in obstructing the organs of respiration.

Coal-dust in a state of extreme comminution and suspended in the air may also, in very dry localities and with certain kinds of coal, undergo rapid combustion under the influence of the flame of a shot, or of a slight fire-damp explosion, and produce a veritable report, and sometimes it may set fire to the timber on which it has been deposited in more or less thick layers.

The principal gases which find their way into the workings through the visible fissures, or through the pores in the rock, are

carbonic acid, carburetted hydrogen, and sulphuretted hydrogen. The fissures and pores referred to were shown in the last chapter to be permeable to water, and they are therefore *à fortiori* permeable also to gases.

Carbonic acid gas is very often found saturating the ground, as it were, especially in countries which have been the scene of volcanic action. This is the case in many mines in Auvergne.

Light carburetted hydrogen, which is also called fire-damp and marsh-gas, has been met with in salt works, but it plays a more important part in coal-mines. It appears to be the product of certain not yet well-defined processes which the vegetable matters out of which coal has been formed have undergone in the presence of water.

This gas is not found indifferently in all the seams, whilst its presence appears to be less strictly due to the quality of the coal than to the topographical conditions of the mine. It is less abundant near the outcrops, or where the superincumbent strata, forming the roof of the seam, are more intersected with fissures, and thus give it a ready passage to the surface.

We must suppose that fire-damp exists in a state of more or less tension in the pores of the coal, and that it is set at liberty when they are exposed. In escaping it breaks the envelope of the tiny cells in which it has been confined with a noise similar to that made by water commencing to boil. This sound, which is called the *song of the fire-damp* (*chant du grisou*), is very audible in a working place in which the gas is given off in considerable quantity. Other things being equal, the amount of fire-damp disengaged increases with the rate at which the coal is being worked away from the face; for it comes principally from the fresh surfaces exposed in the act of bringing down the mineral.

A given face of coal will discharge no gas, or, at any rate, only a small quantity after it has been allowed to stand for a few days. This is due to the fact that the minute cells, near the face, have had time to empty themselves.

Consequently, a mine which produces fire-damp gives off a quantity of that gas which increases slowly with the extent of the workings, but is, on the contrary, in direct proportion to

the area of fresh surfaces exposed day by day, and this area is evidently proportional to the daily output of the mine. Thus, when the means of ventilating are limited, it is sometimes the amount of fire-damp given off which limits the possible output.

The pressure at which the gas is confined in the pores is very considerable. For, if we take a small piece of coal freshly-broken off from the face of a fiery seam, and place it under a test-tube over water or mercury for a few hours or for a day or two, we shall observe that it gives off three or four times its own volume of gas. This would already indicate that the pressure was equal to three or four atmospheres, because that pressure would be required to bring back the volume of the gas to that of the piece of coal; but this is far too low an estimate of the pressure, since the gas did not originally occupy a space equal to the size of the piece of coal, but merely the free space afforded by its pores.

As a natural result, all the fissures which communicate with a seam of coal are filled with fire-damp in a high state of tension, provided they are otherwise hermetically closed.

Thus it is that fissures in the ground often give off gas in a sinking-shaft or in a cross-measure drift in the Coal Measures, and cases might be mentioned in which workmen using naked lights have been burnt in drifts in barren ground exactly in the same way as they might have been in working-places in the coal.

These accidental emanations of fire-damp are known by the name of *blowers* when the amount of gas is considerable, and when it continues to be given off for some time. Under certain conditions blowers may continue to exist for months, or it may be years, but, in the long-run, the same fate overtakes them all; that is to say, they cease to give off gas. They have sometimes been made use of for lighting purposes, the gas being collected in pipes and burnt in ordinary burners.

The conditions favourable to the production of a large blower are: the existence of a great fault, closed towards the surface, with spaces left unfilled with rock, and cutting across several seams of coal, which give off fire-damp over a long range of the coal-field. At its intersection by the fault, each seam of coal presents two faces to the fissure, each face being similar to a very extensive long

wall face. The total surface available for the emission of gas is, therefore, very great, and it begins to act again as soon as the fault has been tapped by a working place and the accumulation of compressed gas has been discharged.

The *first* effect of tapping such a fault is a sudden disengagement of a very large quantity of gas, due to the pressure pre-existing in the cavity; the amount of pressure is sometimes rendered evident by large blocks of coal being hurled out just as the man strikes through into the fault with the pick. The *subsequcnt* effect is the persistent escape of gas during a certain time, in consequence of the great area of the surfaces from which it begins to be given off as soon as the pressure is reduced.

(552) The fire-damp found in a mine is not derived solely from the fresh coal at the faces, or from faults which have been pierced in the manner described above. For instance, in mines worked by removing pillars and allowing the roof to fall, it is found that the irregular empty spaces left behind become reservoirs of fire-damp mixed with atmospheric air in every proportion. The gas disengaged in these places may either come from the coal lost under the falls during the operation of stripping, the amount of which increases with the thickness of the seam, or it may be due to the existence of a thin seam, a *rider*, in the roof, which may be exposed by the heavy falls.

Reservoirs of this kind are ready at every instant to discharge part of their contents into the adjoining pillar workings; and indeed, the amount given out in this way is very appreciable whenever a sudden and considerable diminution of barometrical pressure occurs.

It is thus a well-known fact among miners, that where pillar-working is carried on, from the limits of the field backwards towards the shaft allowing the roof to fall, the state of the ventilation is most intimately connected with the variations of the barometer.

It is said that, when the barometer falls, the bad air *comes out of the old workings* (*goaf*), and when it rises the bad air *goes back* again. These expressions represent very exactly the actual events that

occur. It is easy to conceive that the volume which passes from the *goaf* into the working places, or *vice versâ*, may be very considerable. If we looked at the part where the roof has fallen, we might suppose, at first sight, that, at a short distance from the present workings, the void had been completely filled. But this filling, caused by the breaking up of the rocks, simply renders the void *less apparent*—only spreads it out, as it were, through the whole height of the fall, and does not prevent its existence. The empty spaces therefore, in reality, form a reservoir, which may sometimes have a capacity of *many thousand cubic yards.*

But a barometrical variation amounting to half an inch causes a corresponding variation in the volume of the gas which fills this vacant space of $\frac{1}{60}$ or 0·0166; that is to say, a fall of half an inch will cause a volume of gas equal to 16½ cubic yards for every thousand yards of vacant space to flow into the workings, and a rise of the same extent will cause the same volume of air to flow back into the goaf or waste.

Even in a seam worked with stowing, the packed space behind the working places may contain gas, and this can often be verified by making a small excavation in the goaf and introducing a safety-lamp. This fire-damp is given off by the fine coal produced in holing, which is always stowed with the rubbish, or by coaly shale which has been picked out and thrown back. The packed space thus constitutes a limited reservoir, in which gas is produced temporarily; but it is, nevertheless, always ready to give off a portion of its contents when their volume is increased by a fall of barometric pressure.

The influence of variations of the barometer has been denied, and it has been said that a difference of pressure of half an inch is too insignificant to produce any effect in presence of the high tension of the gas pent up in the coal, which may amount to several atmospheres.

There is here a confusion of ideas which it will be well to clear up.

It may perhaps be right to say, that the amount of the gas which is *given off* by the coal will be sensibly the same, whatever be the *actual* barometric pressure, *so long as that pressure does not*

vary; but if it diminishes or increases at the mouths of the orifices from which the gas is escaping, *the first effect* is an increase or diminution of the rate of flow. This effect, however, will disappear almost entirely as soon as the alteration of pressure, or altered pressure, has become established in the small capillary canals.

Thus it must be said, strictly speaking, that although what may be called the normal discharge of gas may, to some extent, be independent of *the degree of pressure*, yet it varies temporarily with this pressure; but this variation is much more marked in regard to the gas *already set free from the coal*, which is accumulated in the old workings and among the stowing, where it follows Mariotte's law.

(553) To sum up what has been said above, we have seen that in the workings of a mine we may expect to find:

1st. Air which is somewhat different from ordinary atmospheric air, in so far that it is generally saturated with watery vapour, and contains a smaller proportion of oxygen relatively to its nitrogen.

2nd. In addition to this we have the following substances existing either in the form of gas properly so-called, or of smoke, or of dust, the origin of which was explained above.

Carbonic acid.

Light carburetted hydrogen, either pure or more or less mixed with heavy carburetted hydrogen.

Carbonic oxide, and all the products, hydrocarbons or others, which result from a fermentation or an incomplete combustion of coal.

Sulphuretted hydrogen, which ought to be mentioned less on account of its abundance than on account of its specially deleterious nature, which renders it very dangerous even in insignificant quantities.

All the gaseous and solid substances which are produced by the combustion of powder.

Vapours or dust, sometimes deleterious, like those of mercury and arsenic; sometimes without a specially poisonous action, like the dust of most kinds of mineral, but always more or less hurtful

to health when they are present in large quantities, and having the property, in this case, of becoming dangerous if they are combustible.

Lastly, miasmata, which, even in too small a proportion to be perceptible to analysis, are often more terrible in their effects than sulphuretted hydrogen.

Such are the numerous causes of the alteration and unhealthiness of the atmosphere in which the miner has to live and carry on his daily avocations.

(554) This might perhaps be thought the proper place to introduce a discussion of the law known in physics as that of *the diffusion of gases*, in virtue of which any two gases whatever, which are placed in enclosed spaces communicating with each other, end by being thoroughly mixed and constituting a perfectly homogeneous mass, which, when once produced, remains in the same state for an indefinite length of time, without one of the gases becoming subsequently separated. The result of this would be, that the air of a mine, which is always in communication with the atmosphere by at least one channel, ought not to differ from ordinary atmospheric air in its compositon.

This would be the case if, after the alteration of its composition had been once produced, the causes which led to it ceased to operate; and it is clear that an *abandoned mine*, in which none of these causes existed, would, under the more or less sluggish action of diffusion, end, in the long-run, by becoming filled with ordinary atmospheric air.

As a matter of fact, however, this is not by any means the case; for the causes of alteration, far from being momentary in their action, are, on the contrary, essentially permanent in a mine in course of being worked. Furthermore, the power of the most important of these agencies is in a more or less direct relation to the activity of the output of the mine, and that itself obviously depends on the number of workmen employed and the extent to which the working places are developed.

If we suppose the air in a mine to be stagnant, then the effects of diffusion would bear a certain relation to the forms and dimen-

sions of the various workings, and the section and length of the gallery or pit, which places them in communication with the external air. It might, therefore, happen that, in certain particular parts of the mine, or even in the whole mine, diffusion would have *less effect* than these deteriorating agencies, and that, in consequence, the atmosphere of a given working place, or of the whole mine, would become more and more vitiated until at last it would be unable to support the respiration of men or the combustion of lamps.

This is generally the result which would be produced if the air were, in reality, stagnant as we have supposed, or almost stagnant.

We must conceive also in this case that, independently of the general effects produced in the whole of a mine by the disappearance of part of the oxygen and the addition of substances foreign to the normal constitution of the atmospheric air, certain local effects would be produced at the very spot where the alterations were taking place, and these effects would vary according to the chemical and physical properties, and the quantities of the substances which were becoming mixed with the air of the mine.

(555) These special effects, and the means of guarding against them, should be perfectly well known to the miner.

If we have to do with the disappearance of oxygen and its replacement by carbonic acid in consequence of the respiration of the men and the combustion of the lamps, the conditions under which these phenomena take place are of such a nature that we may consider diffusion to operate immediately.

Air which has been breathed once contains 79 parts of nitrogen, 17 or 18 parts of oxygen, and 3 or 4 per cent. of carbonic acid. When this is its composition it is already almost irrespirable, and lamps will hardly burn in it; and before the proportion of carbonic acid reaches 10 per cent. the lamps are extinguished, and the men are in imminent danger of asphyxia. These two circumstances, the extinction of the lamps, and the dangers of asphyxia to the men, always accompany each other; and it can be said, that wherever lamps will still burn, however languidly, the men may be easily

fatigued, but they are not in immediate danger of asphyxia, and they have generally time to withdraw themselves.

When carbonic acid comes from some other source than the one we have just mentioned, if, for example, it flows into the mine from a fissure in the ground, and at the temperature of the surrounding air, the first effect produced is purely hydrostatic. The carbonic acid, whose density compared with that of atmospheric air is 1·524, *falls* in the air at the point where it emerges, as one liquid of greater density does in another of less density, and in this way it reaches the lower parts of the workings. It would not rest in this position, however, and diffusion would ultimately produce a perfect mixture with the air if its discharge were to cease. But if it is continuous, and if diffusion acts more slowly in *taking away* the gas than the stream brings it in, and this is the case we are now supposing, an atmosphere of more or less pure carbonic acid, and of greater or less extent, will continue to lie along the floor of all the workings in which the outflow of gas is taking place.

This is exactly what happens in the *Grotto del Cane*, which is known to all who have visited Naples. This grotto is merely a cave, which communicates with fissures from which volcanic emanations of low temperature, composed principally of carbonic acid, are given off. This gas forms a sheet, or a kind of bath, along the bottom of the grotto, which is deep enough to suffocate small animals, such as dogs, whose heads remain in it, but too shallow to have any effect on men whose heads are above its level.

Carbonic acid suffocates, or stifles, because it cannot furnish the lungs with the oxygen necessary to change venous into arterial blood; but it does not appear to possess any deleterious or poisonous action, although this opinion is not universally held. This, however, is not a matter of much importance to the miner, who need only know that it is irrespirable, and that he ought not to allow it to accumulate.

The appearance of carbonic acid is by no means rare, for it often exists in great abundance in the bosom of the earth, as is rendered manifest by the mineral springs charged with this gas, which are to be found in so many localities. If water containing carbonic acid meets with empty cavities in travelling underground, it gives

off a portion of its gas; and the miner, who, in his turn, cuts into such a cavity, or even into a simple fissure communicating with it, observes a discharge of the gas into the working places.

An occurrence of this kind is more especially common in localities where springs giving off gas are plentiful. This is observed in many of the mines of Auvergne, where these mineral springs form the last reverberation of the volcanic action to which that country has been subjected at a period which, geologically speaking, is comparatively recent. The presence of carbonic acid sometimes renders the ventilation of these mines a matter of some difficulty.

(556) Fire-damp is, as we have said, light carburetted hydrogen, or a mixture of light and heavy carburetted hydrogen in which the former gas greatly predominates. It is similar to carbonic acid in one respect, that, on flowing into a working place it begins by spreading itself out like a liquid, but instead of doing so along the floor, like that gas, it takes up its position along the roof. This is due to the fact that the two gases of which fire-damp is composed have the respective densities of 0·555 and 0·980, and their mixture, in every proportion, is, therefore, less dense than atmospheric air. Fire-damp would, therefore, produce just the opposite phenomenon of the *Grotto del Cane.* Thus, in a place which contains it, respiration can be carried on best next the floor, and the men ought to keep their lamps in that position. In such a place we may find nearly pure air on the floor, and nearly pure gas at the roof, and in passing slowly through the intervening space from the one position to the other, we meet with all the intermediate mixtures, and reproduce the succession of phenomena which are manifested by these different mixtures.

Like carbonic acid gas, fire-damp cannot support respiration, and an excavation which contains a sufficiently large proportion of it is quite as dangerous for men as if it contained carbonic acid. There is this important difference, however, between the two cases: if a man drops down suffocated in a space containing fire-damp, the fall itself tends to bring him out of the asphyxiating mixture into purer air; while, on the other hand, if the same space con-

tained carbonic acid he would be in a worse position after falling than before. With regard, however, to the combustion of the lamps, carbonic acid and fire-damp are essentially different.

Pure fire-damp, without any admixture of air, extinguishes lamps in the same way as it suffocates men, because, since it *contains no oxygen*, it is just as incapable of supporting combustion as carbonic acid gas in which the oxygen is in a state of combination. But it is itself combustible, because the two elements composing it (hydrogen and carbon) have each a strong affinity for oxygen. Hence, when it is mixed with atmospheric air, in suitable proportions, it burns if the mixture is raised to the requisite temperature.

A red-hot iron, or a red-hot coal, or, in general, *an incandescent body without flame*, does not easily ignite it, because the contact of the gaseous mixture with these bodies does not take place at a sufficiently large number of points. It requires the presence of a substance burning *with flame*, like the oil which saturates the wick of a lamp, because the flame itself is burning in a *gaseous state*, and is susceptible of mixing itself intimately with other gases.

The effects produced are very different with different mixtures of the gases.

If the fire-damp is present in *minute quantity*, it burns only where it is in close contact with the flame, because the products of combustion are immediately cooled below the point of incandescence, and become drowned as it were by the oxygen and nitrogen in excess.

If the fire-damp is in *very large quantity*, the same effect is produced from a similar cause, except that it is the excess of fire-damp and the nitrogen, which immediately cool the products of combustion.

In the first case, the lamp continues to burn without displaying any unusual phenomena; in the second case, it is immediately extinguished in the same way as it would be in carbonic acid. But between these two extremes there are a number of intermediate mixtures, which produce a series of phenomena with which the miner ought to be familiar.

Suppose, for example, a working place which contains nearly pure air on the floor, and nearly pure fire-damp at the roof, and

between the two a series of intermediate mixtures in every proportion, passing gradually from the one to the other.

A lamp placed on the floor will burn, as usual, without anything remarkable taking place. On raising it, and taking care to shade the light from the eye by means of the hand, the top of the flame is seen to become surrounded by a thin bluish halo or *cap;* this cap, which is hardly visible at first, enlarges itself as the lamp is raised up, while at the same time the flame becomes elongated and smoky.

The halo is the gas which burns in contact with the flame, without the combustion being able to propagate itself through the mass. The alteration which the flame itself undergoes is caused by the gas produced from the oil of the wick burning less rapidly, and less completely, on account of the scarcity of oxygen.

By-and-by the *cap* increases to such an extent that the cooling action of the air no longer suffices to prevent the combustion from spreading, and then the flame is propagated slowly, like a kind of *ignis fatuus,* through the whole mass.

On raising the lamp still higher, the propagation of combustion becomes more and more rapid, until it is, as it were, quite instantaneous; that is to say, the mixture reaches a point where it becomes detonating in the highest degree.

Above the last point, if the detonation has not disturbed the mixture, it will be observed that the increase in the proportion of gas in the mixture decreases more and more the force of the explosion, and, after the whole of the phenomena described above have been observed again in the inverse order, the lamp is at last extinguished.

The first phenomena do not begin to manifest themselves, or, in the language of miners, the gas does not *show* until there is about 3 or 4 per cent. of it in the mixture.

With 6 per cent. the flame of the lamp is very elongated, and the cap large.

With 7 or 8 per cent. ignition is propagated slowly throughout the whole mixture.

With 12 or 14 per cent. the propagation is instantaneous, and the explosion attains its maximum energy.

With 20 per cent. the same phenomena occur as with 6 per cent.

With 30 per cent., finally, the lamp is extinguished.

It is, of course, understood that these observations are made with safety-lamps, which we shall discuss further on. We will merely remark here that the most ordinary form of these lamps consists of a cylinder of wire-gauze surrounding the flame, and acting like a refrigerator upon the incandescent gas which traverses its meshes, extinguishing it, and rendering it unable to transmit ignition to the outside atmosphere.

From the behaviour of the *cap* inside this cylinder we can judge of the composition of the gaseous mixture. With 12 per cent., for example, the cylinder is entirely filled with brilliant flame, and becomes red hot almost instantaneously.

We shall return to these details in speaking of the lighting of mines.

(557) We will content ourselves here with pointing out the dangers to which the presence of this gas exposes the miners, if, in spite of all the precautions which ought to be taken, a body burning with flame accidentally comes into contact with a more or less explosive mixture.

If the volume of the gaseous mixture is not great, and if it is disseminated over a considerable area of the roof of the working place, or, again, if it contains an excess of fire-damp or of air, so that the combustion or ignition is propagated slowly, the accident will have a purely local character.

The combustion is propagated all along the space occupied by the gas, and principally in a direction opposite to the air-current. The workmen who are in the working place, or above it, are burnt more or less; sometimes the timber is set on fire if it is very dry, or if it is covered with fine coal-dust; sometimes, finally, the jets of gas which issue from the coal or rock are ignited. It then happens sometimes, after an accident of this kind, that the face is covered with small blue flames, which run along its surface, and would soon set fire to the coal if care were not taken to extinguish them immediately.

The mischief, however, goes no further; an accident might thus

take place in one district of a mine without being felt in another district of the same mine.

It is quite different in the case of great explosions, which occur when many cubic yards of air and gas, mixed in the proportions required for an instantaneous propagation of the flame, are ignited by some accident; it may be by an open light, or a defective safety-lamp, or a shot fired in a working place containing fire-damp, &c. &c. The body of gas, which is suddenly heated to a very high temperature, tends to occupy a very large volume, which may be ten times what it was originally. The result is a violent current, which is felt equally on all sides of the point where the explosion happens, and propagates itself along the galleries like a sound-wave in a tube.

Experience shows that the movement produced in this manner is sufficiently violent to overturn everything it meets in its way; air-doors are destroyed, men are knocked down or dashed against the sides of the galleries, and the timbering is torn out, it may be, for the whole length of a gallery. It may even happen, sometimes, that these underground hurricanes extend to the shaft and as far as the surface, tearing out the brattice, disarranging the guides, unroofing the buildings which cover the mouth of the pit, damaging the engines, &c.

The propagation of these waves, from the origin of the explosion, and the rapid cooling of the incandescent gases in contact with the sides of the galleries, and due to the very fact of their expansion, rapidly produce a certain vacuum at the origin, which creates a second current travelling in the opposite direction to, but less intense, than the first. The latter current in its turn produces a certain degree of compression, which gives rise to a third current in the same direction as the first, and so on. Equilibrium is, therefore, established by a series of alternating currents whose intensity decreases rapidly.

At the same time that the explosion has destroyed the regular ventilating current by breaking doors and brattices, the air is rendered unfit for breathing by being deprived of its oxygen, as well as by the clouds of thick dust which the currents have raised in all the workings. Furthermore, the same causes suddenly

draw out gases from the old workings which may be explosive or irrespirable.

Those workmen, who have escaped from the effects of a great explosion, are, therefore, far from being out of danger, and, generally indeed, they constitute the larger number of victims. They are asphyxiated by the want of oxygen, or choked by the thick dust, or killed by *secondary explosions*, which often follow in the wake of *a great explosion.*

Secondary explosions are liable to occur without warning, and always render the work of saving life an exceedingly hazardous undertaking after a great explosion. They may be due to the fact that timber or coal has been set on fire by the flame of the first explosion, and that, the regular air current having been destroyed, bodies of unconsumed explosive gas are carried accidentally to one of these points, or even possibly to the ventilating furnace, if the latter is not well isolated, or if it has not been destroyed and extinguished by the principal explosion.

(558) Carbonic oxide, the different hydrocarbons, and various empyreumatic compounds, are produced only when the combustion is incomplete; this happens, for instance, when spontaneous combustion has arisen in part of the mine, and attempts are made to isolate it by barriers which are constructed as air-tight as possible.

Barriers of this kind are never absolutely air-tight, and besides, the air finds access to the fire through fissures in the roof of the seam, or through the abandoned pillar-workings. But air does not reach the burning mass in this way except very slowly and in small quantity. It finds itself in the presence of a great excess of combustible matter, and the combustion is, therefore, necessarily incomplete. All the products of a combustion of this kind are characterised by a peculiarly pungent odour, and when they are contained in the air even in a very small proportion they have a very poisonous effect; furthermore, they may form explosive mixtures with air. Thus when a barrier is opened for the purpose of trying to penetrate towards a fire with the view of still further restricting its limits, we must expect to meet with an atmosphere

which may be very *poisonous*, and at the same time *explosive*. All the precautions should be taken with these two contingencies in view.

(559) Sulphuretted hydrogen and the various miasmata may also have an active poisoning effect, which commences to make itself felt when these matters are mixed, even with such a large proportion of air as to render them imperceptible to the sense of smell. In general the only method of rendering them inoffensive is to dilute them with a sufficiently large body of air, and sweep them away. It is their constant presence in badly-ventilated mines which acts in the long-run upon the constitutions of the miners, and develops that tendency to anæmia which affects the working population of certain coal-mining districts, and did so in a more marked manner before the introduction of improved ventilating appliances.

Sulphuretted hydrogen may be formed under all circumstances in which sulphur and hydrogen come together in a state of great subdivision, or in the nascent state. Thus, for example, it may be produced during the slow oxidation of pyrites in the presence of water. Or, again, it is one of the products of the decomposition of certain kinds of animal matter which contain sulphur. Lastly, it is contained in many mineral springs, which are more or less saturated with it, and it is natural to expect that it should occasionally be disengaged through fissures in the ground.

In Sicily it is met with in solution in the waters of the sulphur mines, and sometimes in such a quantity as greatly to hinder the workmen unless the ventilation is exceedingly good.

Miasmata are effluvia given off by men and animals, or by their evacuations, and, in general, by all animal and vegetable substances in the mine, including, in the case of more than one coal mine perhaps, the mineral itself that constitutes the object of exploitation.

(560) Smoke or dust, that is to say, substances that are not gases, but are simply held in suspension in the air, are, in the

first place, produced by blasting; in this case they consist of the sulphate and sulphide of potassium, and a small portion of the powder itself, which escapes the combustion and is thrown out. Gunpowder smoke has a disagreeable odour and a pungent effect on the respiratory organs, intense enough to render a working place almost uninhabitable immediately after a shot has been fired in it, at all events until it has dissipated to some extent.

Dust in suspension, derived from the mineral which is being worked, will usually be harmless; that is to say, it will not have a special physiological action due to its *chemical composition*. But it will act *physically* or *mechanically*, in contributing, in the lapse of time, to clog the lungs; and the intensity of its action, in this respect, will depend on its abundance and the constancy of its presence in the air.

We have already said that certain kinds of dust have a special poisoning action, such as the dust met with in quicksilver mines, which acts in a sufficiently marked manner to prevent continuous labour underground. Thus at the Almaden mines the same workmen are employed in the mine and at the surface alternately.

In certain coal mines, and especially in dry districts, very fine coal-dust is always suspended in the air, or great clouds of it are raised immediately when the air is much disturbed. It appears to be established at the present day, as we have said above, that the impalpable dust of *certain kinds of coal*, when mixed with atmospheric air, behaves almost as if it were a combustible *gas*, or, in other words, it gives rise to phenomena similar to those produced by an atmosphere charged with fire-damp.

It is easy to conceive, moreover, that the effects of fire-damp and coal-dust can, in a manner, be superposed one on the other, and that the ignition of a small quantity of fire-damp at any point may raise and set fire to clouds of coal-dust, and greatly extend the area of an explosion, which without such an addition would have been relatively harmless.

An attempt is made in this way to explain the extensive and destructive explosions which appear sometimes to be out of all proportion to the quantity of fire-damp that might reasonably have been expected to have accumulated at any given point.

(561) We have seen, from what precedes, what are the various results that may be produced in a mine, in which the air is renewed by diffusion only, at those points where permanent causes tending to *vitiate it* are acting more rapidly than diffusion can *purify it.*

It is necessary in this case to assist the action of diffusion by some other supplementary means.

We might suppose that chemical agencies could supply the desired want. For example, milk of lime will absorb carbonic acid, or chlorine can be employed either in the state of gas or in the form of chloride of lime to destroy sulphuretted hydrogen and the miasmata.

It has happened more than once that people who were strangers to practical mining have highly extolled these means of overcoming the difficulties, or have thought it would be a comparatively simple matter to collect the fire-damp at the point where it is given off, and either to burn it on the spot or conduct it to the surface and let it escape into the atmosphere, or use it as a means of lighting.

It is easy to form an estimate of the true value of these ideas.

Milk of lime has only a temporary and local action, and it could not be renewed when necessary at all the points where it would be required again. An excess of chlorine in the air would produce mischief of the same kind as that which was sought to be remedied.

The isolation of fire-damp, which is both practicable and practised at all places where it issues in large quantities in the form of blowers, is quite inapplicable in regard to what may be termed the *normal fire-damp* which *oozes* out, as it were, from all the pores in the face of the workings in the form of infinitely small jets of gas.

In the absence of sufficiently powerful chemical means, therefore, the supplementary action required to assist diffusion will be obtained by *the addition of a new mass of air,* which will sufficiently dilute the gas and render it imperceptible, or at least harmless, and by *the successive renewal of this entire mass,* with such a degree of rapidity that the quantity of noxious gas, of whatever

kind, that is carried away in a certain time, may be at least equal to the quantity that can be given off in the same interval of time.

In a word, we apply to the ventilation of a mine the process which is universally adopted in practice for the purpose of rendering any confined space habitable in which some permanent causes are at work in vitiating the air.

The art of producing this current of air, and maintaining it in the direction and of the proper volume required, and the knowledge of the means whereby it is made to circulate in the necessary proportions amongst the various districts of a mine, constitutes the art of ventilation.

In mines of small extent, in which the working places are very roomy, and communicate with the outside air by many openings, it may happen that ventilation is so easily produced that it takes place *of itself*, as it were, and that the miner does not need to trouble himself about it. Diffusion may have a sufficiently purifying effect, or, more likely, some special circumstance determines a current of air in a certain sense; it will then be seen that the air enters by one of the openings and escapes by another, and this feeble current is enough to complete the effect of diffusion.

But these facilities of ventilation do not always present themselves; on the contrary, it is more often the case, and notably in large collieries in which fire-damp is given off, that all the resources of the art of ventilation are barely sufficient to render the mines everywhere as safe and healthy as they should be at *ordinary times*, and that, in spite of all endeavours, they do not entirely prevent the dangers arising from *unusually large* eruptions of gas.

A mine of this kind cannot be kept in full work unless the air-current is maintained unceasingly, and any accidental stoppage of the *artificial means*, which reduces the mine to what may be called its *natural means* of ventilation, should be the signal for a prompt retreat of all the workmen within a very short space of time.

After these general remarks we shall consider the rest of the subject under the following heads:

1. The circumstances that may tend to produce an air-current travelling in a settled direction in a mine, or what is called its *natural ventilation.*

2. The mechanical or other means whereby, in the absence or insufficiency of the natural current, *artificial ventilation* can be produced.

3. The principles and the processes by means of which the air-current can be subdivided (*split*) amongst the different districts of the mine according to their requirements.

§ 1. On natural ventilation.

(**562**) If we consider any mine which communicates with the outside air by means of two distinct openings, and in which an air-current circulates *of its own accord,* we find that the air enters by one of the openings, passes through the network of galleries, and escapes by the other opening.

The whole passage traversed may be compared to a kind of large siphon whose two branches terminate at the points of entrance and exit. If we consider any point of this siphon, we find the air occupying it to be possessed of a density which results from its temperature, its composition, and its pressure; and the movement of the air through the siphon takes place in the same way as it would do if it consisted of *a succession of incompressible fluids possessing at each point the density of the air occupying that point, and subjected at each end of the siphon to the given pressures.*

This simple notion, and the application of the most elementary rules of hydraulics, are sufficient, with the aid of the observations which follow, to enable us to foresee and explain the various circumstances which occur in practice.

As regards the temperature at any given point in a mine, we have to distinguish between that of the rock itself, and that of the air which circulates at that point.

It is well known that, at a little depth below the surface, we arrive at a point where the temperature is *invariable* throughout the year. This is the case all over the globe, and the invariable temperature

referred to is the mean temperature of the year at the surface at the place of observation. In sinking below this point again we find an increase of temperature which varies according to circumstances still imperfectly understood, but amongst them may be reckoned the peculiar conductivity of the rock, which is an important factor. This increase amounts to 1° Fahrenheit for every 45 to 55 feet of vertical depth sunk through * (1° C. for 25 to 30 metres). Thus in France, for example, we should have 50° F. (10° C.) near the surface, and from 73½° to 79° F. at a depth of 430 yards (23° to 26° C. at 400 metres).

With a sluggish air-current the mass of air has a tendency to assimilate the temperature of the rock at every point. The presence of the workmen and their lamps, and the various chemical changes going on, tend also to augment it. In wet places the presence of water which infiltrates from the surface tends to diminish it. In accordance with these facts, therefore, the temperature of the interior of a mine is always higher than that of the outside air during winter. During summer, again, the difference may be sometimes on the one side, sometimes on the other according to whether we consider the ventilation during the night or by day; but in either case the absolute difference is smaller in summer than in winter.

As regards *the influence of the composition of the air of a mine upon its density*, we may say that carbonic acid tends to increase its density; but, on the other hand, watery vapour, with which the air of mines is usually saturated, tends to diminish it; and the same can be said with regard to fire-damp, which is in general a more important factor in a coal mine than carbonic acid.

Lastly, if we consider *the pressure*, it may be said that it can be found at any given point by the ordinary rules of hydrostatics, from the pressure which exists either at the top of the down-cast or up-cast pit. In the first case we must deduct from the result so obtained, and in the latter case we must add to it, the whole pressure required to produce the variation of the *vis viva*, and to surmount the resistances of every kind between the top of the

* In the English Coal Measures the increase is generally taken as 1° Fahrenheit for every additional 60 feet of depth.—*Translators.*

down-cast pit and the point of observation, or between that and the top of the up-cast pit.

(563) Keeping these principles in view, it is easy to see what takes place in the various cases we may have to consider.

If, for example, the two orifices are at the same level (fig. 440), and if the shafts leading from them are of equal depth, the network of galleries is comparable to a siphon with two branches of the same length, and there is no reason *à priori* why the air-current should take any definite direction.

But we shall suppose that some accidental circumstance or other has determined the current in the direction shown by the arrow. This will be the case, for example, if the pit A is dry, and the pit B wet, either naturally, or because it contains pumps. The shaft, down which water is dropping, is in this way made the downcast, as the air is drawn and forced down by the drops of falling water.

If the mouths of the shafts are at the same level and their depths different (A D and C B, fig. 441), it is again by the pit B that the air will tend to descend, and for the following reasons: If, on the one hand, there are pumps in the mine, the lodgment for water will be at C, and consequently the pumps will be in the shaft C B; if, on the other hand, we consider the two equal parts of the siphon A D and B *d*, and the partial siphon *d* C D with unequal branches, we see that the two first are in equilibrium, but the case is different in the partial siphon in which the men are at work, and fire-damp is disengaged, and the air is being heated by the warmth of the men's bodies, their breath and their lamps, and its composition is being changed. Both influences are acting in the same sense, and are going on simultaneously. The mean density in the inclined branch C D is therefore less for these two reasons than that in the vertical branch *d* C; consequently equilibrium is impossible, and a movement is produced in the direction indicated, or from the pit B towards the pit A.

If the two shafts have their mouths at different levels (fig. 442), we must draw through B and A the two horizontal lines BB′ and AA′; then the branch BCB′ comes under the two preceding cases,

and the current would tend to flow in one direction or the other, according to the circumstances that have been pointed out. But we have further to consider the two columns AB′ and A′ B, which are of equal height, but at different temperatures, the former having the temperature of the external air, the latter that of the ground at a small depth below the surface. As, moreover, there exists at the points A and A′ the same atmospheric pressure, we should conclude that the pressure at B will be superior or inferior to the pressure at B′, according as the external air is warmer or colder than the air in the column AB′. We shall, therefore, have a current from B towards A in winter, and from A towards B in summer.

Hence we deduce the following theorem:

When a mine communicates with the surface by means of two openings situated at different levels, and when its workings are situated below the level of these openings, it will be ventilated naturally by a current of air which goes from the lower towards the higher opening in winter, and from the higher towards the lower one in summer.

(564) One general remark ought to be made regarding the natural currents, which are produced in the various cases to which figures 440 to 442 refer, according as it is summer or winter, or, more exactly, according as the exterior temperature is *lower* or *higher* than that of the mine; namely, that the weight of the column of air in the downcast shaft *tends to increase*, or, on the contrary, *tends to diminish*, according to the persistence of the current, because the mean temperature of this column tends to approach more and more nearly to the mean temperature which it has when it enters the mouth of the shaft. There is, therefore, this radical and characteristic difference between the currents produced in winter and summer, that the cause *which maintains* the current in winter is more energetic than the cause *which initiates* it, and that the contrary is the case in summer. The former is, therefore, *more stable* than the latter; at the same time it is *more energetic*, because there is a greater difference between the temperatures in winter than in summer; lastly, in winter, the difference between

the temperatures is *always in the same sense*, during both the day and night, whereas in summer, during cool nights, it may become reversed, and produce a current during the night opposite in direction to the one that prevailed during the day. It happens in this way, that, at the moment the current is reversing its direction, the ventilation is stopped, and this occurs twice a day.

These theoretical ideas are fully borne out in practice, and it is well known that a mine which is perfectly ventilated, naturally, during cold weather, is no longer so in hot weather; and that it will be necessary, for example, after a cool morning, to suspend operations, and bring out the men when the heat of the day begins to be felt, or that it will be necessary to light a ventilating furnace for several weeks, which would be useless in winter, &c.

(565) We see that natural ventilation is determined by some special circumstance if the mouths of the down-cast and up-cast shafts are at the same level, or by the difference of level in the opposite case.

We can produce, or increase, this difference of level by building a chimney over the mouth of one of the shafts, and making it of a *large enough section* not to compel the air to assume too great a velocity, and of *sufficiently thick masonry* that the temperature of the surrounding air will be without appreciable effect upon the temperature of the air in the chimney.

Such a chimney (fig. 443) will stimulate the force of the current in winter in the same way as if the mouth of the up-cast were on the level of its summit at A, and in this way it will fulfil its object. But in summer the result will not be at all the same; for, in this case, the chimney will be traversed by a current of air coming from the outside, and the temperature in its interior will tend to become the same as that on its exterior, and this reduces its effect in a very marked manner. It will, therefore, act in summer only in a very incomplete manner, having no effect except during the morning hours, and onwards until the heat of the day is established. During that time we can suppose that its interior surface is less heated than its exterior one, and thus continues to cool the air which passes through it.

Again, we see that the difference between the currents of winter and summer is in favour of the former; therefore, *in every case*, we can say that the winter ventilation is *more energetic*, *more stable*, and *more permanent* than the summer ventilation. It may be sufficient for a given mine notwithstanding its inevitable irregularities; but the summer ventilation is not generally sufficient, and ought to be aided or supplemented by artifical appliances.

(566) In spite of its necessary irregularities and insufficiencies, the partisans of natural ventilation assert that it is better than artificial ventilation, produced in the way we shall see further on, by furnaces or machines, because it depends upon a fixed state of affairs, which are exempt from the perturbations inherent to human actions, and to the intermissions and irregularities inseparable from the working of machines; and that, after it has been suspended for an instant by any occurrence whatever, it will re-establish itself, so to say, of its own accord.

It is evident that nothing could be better than natural ventilation, if its force and regularity could be assured; but experience, as well as the theoretical consideration set forth above, show that this is not the case. *Intermission* and *irregularity* are, on the contrary, *the rule* of such a system of ventilation; and it is rather for the artificial means that the qualities of permanence and regularity can be claimed.

Derangements of the machinery employed rarely occur; and in case of an unforeseen stoppage, arrangements can be made so that, whatever kind of machinery it may be, the current of air is not interrupted thereby, and in this way ample time can be obtained for taking all the requisite precautions for safety which the situation may demand.

We say, therefore, in a general manner, that, although we can regard natural ventilation as a very acceptable system wherever the circumstances are favourable to it, it would be very advantageous to associate artificial ventilation with it, either for the purpose of stimulating it at all times, or for the purpose of taking its place when it tends to stop, or even to act in a direction contrary to its ordinary one.

As a matter of fact, mines of moderate extent working thick seams, and having several shafts, may be sufficiently well ventilated by a simple natural ventilation.

But the number of mines placed in these conditions is always decreasing; and we can say that all the extensive collieries having a large output like those of Belgium, the North of France, the North of England, &c., and especially those which are fiery, cannot be worked without the aid of artificial ventilation, applied sometimes on the largest scale and with the most powerful means which art can place at the miner's disposal at the present day.

§ 2. On artificial ventilation.

(567) Natural ventilation, as we have seen, depends upon the difference of temperature possessed by two columns of air occupying respectively the down-cast and up-cast shafts. The first means which presents itself of increasing ventilation consists in augmenting the temperature, and, consequently, decreasing the density of the ascending column.

A simple and natural method of obtaining this result is to make either the whole of the current, or a part of it, pass over a fire, the portion of the current so heated being again united to the main body.

This fire, which is called the ventilating furnace, is usually placed in such a position as to act in the direction of the winter current. It maintains the current in the same direction during summer also, the increase of temperature being made sufficiently great to preserve the same difference of temperature between the descending and ascending columns as in winter.

The natural position for a ventilating furnace is the *point at the bottom of the upcast shaft, where the current arrives after having circulated through the workings.*

If the furnace were placed somewhere in the workings, it would have the double inconvenience of rendering that part of the workings between itself and the bottom of the upcast uninhabitable, and of uselessly increasing, to the extent of absolute

loss, the resistances due to friction, which augment rapidly with the velocity.

If it were placed at an intermediate position in the shaft, it would be less efficacious than at the bottom, because the effect of the fire evidently increases with the vertical height of the column which it heats. The fire ought, therefore, to be at the bottom of the shaft, and its efficacy will increase with its depth.

Thus, when the choice of the pit is arbitrary, the deepest one will be taken; and its depth can be further augmented artificially by surmounting it with a chimney if necessary.

The system of placing a fire at a short distance below the surface, or of hanging a simple *fire-basket* a little way down, is, therefore, obviously to be regarded as an eminently defective arrangement, even when the shaft is surmounted by a chimney.

This arrangement, which is represented in figure 444, may be useful in places where the ventilation is easily effected, and then its employment may be justifiable; but it *should not be permitted* anywhere unless the current so obtained is largely in excess of the requirements.

It is necessary then, on every ground, to place the furnace at the point where the return air reaches the bottom of the upcast, and this is the practice in all the large mines of the North of France.

In a simple case, where the upcast shaft is used solely for ventilation, and where the presence of gas is not suspected, the furnace is placed towards the end of a gallery which opens directly into the shaft.

This furnace consists of a simple fire-grate, either single or double, on which a certain quantity of coal is burned. (Fig. 445.)

The combustion is fed by the air of the mine, which passes over or through the grate. The increase of temperature obtained depends on the mass of air and the quantity of coal burned in a given time; and this quantity is, within certain limits, at the disposal of the workman who attends to the furnace.

The gallery, at the end of which the furnace is situated, ought to be enlarged and walled. If the gallery is a cross-measure drift, the walling is in contact with the rock; but if it is in coal, it is necessary to have two concentric arches entirely isolated from each

other (fig. 446). The interior arch serves only to enclose the fire, and the exterior one supports the ground. The intermediate space should be large enough to admit of men going between them to make repairs, and it is kept open at both ends and cooled by a part of the air-current which passes through it, and thus escapes without coming into contact with the fire.

A more complete, but also more satisfactory, arrangement consists in placing the furnace in a lateral excavation made expressly for the purpose.

This excavation communicates, by means of a narrow gallery, either with the general return air-course, or with a special air-current which circulates through only a small district of workings in which it is not liable to receive accidental additions of gas; or, in case of need, with a current of fresh air *coming directly from the surface.* This air supports the combustion, and the hot gases produced thereby escape into the upcast through an inclined flue (*furnace drift*), and there mix with, and heat the general return air current.

The arrangement of the furnace ought to be such that the combustion of the gas is as complete as possible; that is to say, that only carbonic acid is produced, and not carbonic oxide; and the inclined flue should be sufficiently long (about 15 or 20 yards) so that all the gas arriving in the shaft shall be perfectly burnt and extinguished, and, consequently, unable to produce an explosion in case the general air-current happened to become accidentally charged with fire-damp.

When a ventilating furnace is established in these conditions it presents no special cause of danger on its own account, even in the most fiery mines, because it is impossible that an explosive current can come in contact with the flame so long as only fresh air is supplied to it, and so long as the doors are kept shut, which isolate it from the general circulation.

Figure 447, for a description of which we refer the reader expressly to the explanation of the plates, gives an example of the above arrangements as they are established in the mines in the Department of the Nord.

As far as safety is concerned, these arrangements are so complete

that we may consider the employment of furnaces *admissible* even in fiery mines; although, taken in the most rigorous sense, it may be asserted that it is *contrary to principles* to allow a naked light to exist at any point in a mine in which explosive mixtures are liable to be produced at any other point. But it may be said that, with the precaution we have pointed out, it would require more than chance, it would require *actual premeditation*, in order that such a mixture could obtain access to the furnace.

Granting that it is next to impossible to produce an explosion in the normal condition of affairs, it is insisted, however, by some that a first explosion, arising from one cause or another, might destroy the isolation of the furnace, change the distribution of the air-currents, and render it possible for new explosive mixtures to gain access to the furnace; so that, if the furnace did not contribute in any way to the first explosion, it could become the cause of succeeding ones.

This is not altogether impossible; but it is, to say the least, highly improbable, because an explosion of such force as to destroy the doors which isolate the furnace, would also overturn the fire-grate, and scatter its contents, and the isolated fragments of coal would not long continue to burn.

In fine, notwithstanding these criticisms, and in spite of the great consumption of coal to which they often give rise, and although the employment of ventilating machines to which we shall shortly refer is gaining ground, yet furnaces continue to be employed very largely in certain countries, and notably so in the North of England, and in the Ruhr basin. It is still by their means that the *largest quantity of air* is obtained in places favourable to their application; that is to say, with large galleries and a judicious subdivision of the air into partial and semi-independent currents.

In our opinion the employment of furnaces is perfectly justifiable *as long as they are sufficiently powerful*, not only because their first cost is much less than that of ventilating-machines, but, above all, because they guarantee in a higher degree than the best machines a service uninterrupted by stoppages for repairs, and because, lastly, in the rare case of their momentary stoppage, their effect continues for a certain time until the complete cooling of the flue and the upcast shaft has been effected.

(568) An important question which presents itself at this point, is that of the temperature to which it is most suitable to heat the air-current in the ventilating furnace.

In practice it is usually sufficient to raise the temperature of the air that has passed round the workings by 20° to 40° Fahrenheit (10° to 20° C); so that the column of heated air in the upcast has not a higher temperature than 100° to 115° F. (40° to 45° C).

In these conditions of temperature the upcast shaft may, if necessary, be used even as a winding pit, provided that wire-ropes are employed in it. It ought not to be made use of for pumping, however, because a pumping-shaft is always very wet, and drops of water falling down are hurtful to the ventilation. On the one hand, they drive back the ascending air, and, on the other hand, they cool it, forming at the same time watery vapour, and depriving the air of its sensible heat.

If this increase of temperature of 20° to 40° F. is not sufficient, it may be advisable to go further; but it should be well understood that, in proportion as we do so, the quantity of air which circulates in the mine will increase *less rapidly*, and the quantity of coal consumed much *more rapidly*, than the accession of temperature, whence it follows that the useful effect of the fuel decreases in a very important ratio.

In order to show this in the most simple manner, we may take the formula of No. 381 of the *Cours de Mécanique*, which expresses the amount of air drawn through a chimney.

Making $a = 1$, that is to say, supposing there is no contraction at the top, and, in presence of the large amount of friction, neglecting the throttling of the air in its passage through the furnace (which is allowable in the case of a well-arranged furnace placed at the bottom of a deep shaft); and lastly, replacing the length L by the height H, which is its equivalent, the formula becomes

$$Q' = \Omega\sqrt{2g}\frac{1}{a+T}\frac{\sqrt{H(T-t)(a-t)}}{\sqrt{1+2g\frac{X}{\Omega}HB}},^{*} \qquad (1)$$

* For meaning of letters see next paragraph.

and if we neglect the height producing the velocity, which is small compared with the head which is absorbed in overcoming friction, the formula becomes

$$Q' = \Omega\sqrt{2g}\,\frac{1}{a+T}\,\frac{\sqrt{(T+t)\,(a+t)}}{\sqrt{2g\frac{X}{\Omega}B}} = \Omega\sqrt{\frac{\Omega}{X}}\sqrt{2g}\,\frac{1}{a+T}\,\frac{\sqrt{(T-t)\,(a+t)}}{\sqrt{2gB}}. \quad (2)$$

In examining it successively under these two forms, we observe:

1st. That the volume of air increases more rapidly than the section, and that, for two similar shafts it tends to increase as the $\frac{5}{2}$ power of the homologous dimensions.

2nd. That the same volume increases with the height, but very slowly; and that it *tends* to become independent of the height when the pits are small and deep.

3rd. That it increases in a rather less rapid proportion than the square root of the difference between the temperatures.

C, the expenditure of fuel per unit of time, is evidently proportional both to the amount of air and the difference of temperature produced in it, and consequently to the product of these two elements, or nearly to the $\frac{3}{2}$ power of the second.

The useful effect of the fuel, that is to say, the quantity of air obtained per pound (kilogramme) of fuel burned, is therefore inversely proportional to the difference between the temperatures.

In accordance with these statements we may draw out the following table:

Successive differences between the temperatures.	Ratio of these differences to the original temperature.	Corresponding volume of air.	Expenditure of fuel.	Useful effect of the fuel.
$T-t$	...	Q'	C	$\frac{Q'}{C}$
9° F. (5° C.)	1	1	1	1
36° „ (20° „)	4	2	8	$\frac{1}{4}$
81° „ (45° „)	9	3	27	$\frac{1}{9}$
144° „ (80° „)	16	4	64	$\frac{1}{16}$
225° „ (125° „)	25	5	125	$\frac{1}{25}$

The principal fact to be remembered in this table is the very rapid increase in the consumption of fuel, in proportion as the exigencies of the case make it necessary to increase the amount of heat supplied to the air during its passage over the furnace.

Hence we conclude that we should quickly reach a consumption of fuel *quite out of reason*, and that if the natural ventilation soon becomes insufficient when a mine is somewhat extensive and difficult to ventilate, it may not always be easy to make up for the deficiency by using furnaces.

(569) It should be remarked that the above formula, which gives the value of Q′, is based upon the supposition that it is the atmospheric pressure which is exerted at the point where the air reaches the furnace; but, in reality, the furnace cannot be supplied with air which has not passed through the workings, and, therefore, its pressure, on its arrival at that point, is reduced by reason of all the resistances it has encountered since it entered the mine. Thus the calculated quantity Q′ is greater than the actual quantity which circulates in the mine; it is the amount which we should find if we supposed that the pressure in front of the furnace had remained, *during the progress* of the air, the same as it was when the air was in a state of rest, or at the *commencement of its movement;* but this is evidently not the case. A reduction of pressure has taken place, which depends both on the actual volume of the air and on the greater or less resistance which it has encountered during its journey from its entrance to the furnace. This volume cannot, therefore, be determined by the simple knowledge of the arrangement of the furnace and of the upcast shaft; the resistances met with before arriving at these points may play a preponderating part. It might be an *impossibility* to obtain with the furnace, however great its temperature, *a certain* volume of air assumed *à priori*, if the circulation in the workings from the top of the downcast to the furnace required a difference of pressure equal to the weight of a column of air of ordinary temperature whose height is equal to the depth of the upcast shaft. (See *Cours de Machines*, No. 382.)

It is this question of difference of pressure which restricts the use of furnaces in low seams with narrow galleries.

We know, in fact, that if we take—

L as the length of any conduit of air whatever;
ω as its section;

X its perimeter;
B a numerical co-efficient found by experiment;
V the velocity of the air in the conduit;
Q the amount passing through the conduit;

the analytical expression for the resistance produced by friction has the form:

$$\frac{X}{\omega}LBV^2 = \frac{X}{\omega}LB\frac{Q^2}{\omega^2} = \frac{X}{\omega^3}LBQ^2.$$

From this we conclude that the resistance *for two similar air-ways* is in the inverse ratio of the fifth power of their homologous dimensions, or that it diminishes very rapidly as the dimensions of the air-ways increase.

Experience entirely confirms this result, and in this way we can explain why it is that, in the Newcastle district, for instance, where the shafts are of large diameter, the seams of coal thick, and the ground so strong as to admit of the formation of large air-ways, it is possible by means of furnaces alone to pass large quantities of air through the workings, amounting in some cases to as much as 200,000 cubic feet of air per minute (90 cubic metres per second); whilst in the thin seams, with weak roof and floor, of Belgium and the North of France, furnaces are often insufficient, and it becomes absolutely necessary to have recourse to machines to produce the required manometrical depressions.

In this way we can explain also how it is that the numerous ventilating machines that have been invented within the last forty years have been almost exclusively designed by French or Belgian engineers, and that their employment has made so little head amongst the English mines, notwithstanding the tendency in that country to have recourse to machinery.

The fact is there was *no necessity* for them in England; whereas in Belgium and the North of France they were *absolutely indispensable*, as soon as large outputs were required, which necessitated proportionately large quantities of air.

(570) Ventilating machines act, in general, either as *exhausting machines* placed at the top of the up-cast shaft, or as *blowing machines* at the top of the down-cast shaft. The first question,

therefore, which presents itself is as to what are the relative advantages of these two systems.

In the first place, for the purpose of comparing them in regard to the amount of motive power required, we shall suppose the mouths of the two shafts to be at the same level, and the current of air in the direction BCA. (Fig. 448.)

We shall imagine an exhausting machine to be placed at A, producing a pressure P_1, less than the atmospheric pressure P_0, or a blowing machine to be placed at B, producing a pressure P'_0 greater than pressure P_0.

In the first case, the machine will exhaust a volume V of air expanded to the pressure P_1, and deliver it into the atmosphere.

In the second case the machine will take the atmospheric air, and compress it to the pressure P'_0, under which it will occupy the volume V′.

The corresponding work will be (*Cours de Mécanique*, No. 335):

$$Tm = P_1 V l \frac{P_0}{P_1} = V\ (P_0 - P_1) \text{ for the first case,}$$

and

$$T'm = P'_0 V' l \frac{P'_0}{P_0} = V'\ (P'_0 - P_0) \text{ for the second.}$$

The condition that the two volumes V and V′ correspond to the *same weight* of air introduced into the workings gives us the two following equations, when we neglect the variations of temperature and apply Mariotte's law, putting ρ and ρ' for the densities which correspond to the volumes V and V′.

$$V\rho = V'\rho',$$

and

$$\frac{\rho'}{\rho} = \frac{P'_0}{P_1}.$$

Moreover, the expenditure of power is proportional to the square roots of the dynamic heads $\frac{P_0 - P_1}{\rho}$ and $\frac{P'_0 - P_0}{\rho'}$; that is to say, we have successively:

$$\frac{V}{V'} = \frac{\sqrt{\frac{P_0 - P_1}{\rho}}}{\sqrt{\frac{P'_0 - P_0}{\rho'}}},$$

$$\frac{P_0 - P_1}{P'_0 - P_0} = \frac{V^2\rho}{V'^2\rho'},$$

and consequently:

$$\frac{Tm}{T'm} = \frac{V}{V'} \times \frac{V^2\rho}{V'^2\rho'} = \frac{V^2}{V'^2} \times \frac{V\rho}{V'\rho'} = \frac{V^2}{V'^2} = \frac{\rho'^2}{\rho^2} = \left(\frac{P'_0}{P_1}\right)^2 > 1.$$

Thus the exhausting machine requires a little more power than the compressing machine, in the ratio of the square of the pressure of the air compressed by the latter, to the square of the pressure of the air expanded by the former.

(571) This is not the only point to be considered, however, nor yet the most important one.

Ventilating machines act by producing a general state of either compression or expansion in the interior of a mine, so that, according to the nature of the machine, the pressure at any given point in the workings is either greater or less than it would be if the air were at rest. Thus the blowing machine increases the pressure at the point in question, the exhausting machine diminishes it; the former tends to hinder the outflow of fire-damp, the latter, on the contrary, favours it. We might suppose this effect to be of no importance in consideration of the high pressure at which the gas is held in the pores of the coal, and this is no doubt the case for *any given condition* of ventilation; but it is no longer so when the *condition is changed*, and it may even become a matter of considerable importance. We have seen indeed that a sudden fall of atmospheric pressure, such as that which takes place in stormy weather, tends to produce in some mines an outflow of gas from the old workings, and that it is necessary to compensate for this by an increased ventilation. When the barometer falls, the increased ventilation means a *greater degree of compression* in the one case, and a *a greater degree of rarefaction* in the other; it tends to *correct* the influence of the barometric depression in the case of a compressing machine, and to *augment* it in that of an exhausting machine.

This circumstance *is favourable to the employment of the former.*

On the other hand, if we suppose that the ventilation comes to a sudden standstill, in consequence of some accident to the ventilating machine, then the first effect of the return to rest is to

restore the pressure at each point to that of repose. There is, therefore, a reduction of pressure in the case of the compressing machine, that is to say, the equivalent of *a sudden fall* of the barometer in the first case, and of *a rise* in the second.

This circumstance is *favourable to the employment of the exhausting machine.*

(572) From another point of view it may be said, again, that it is usually more convenient to have the winding shaft as the downcast, either for the purpose of saving the ropes, especially if they are made of hemp or aloe fibre, or because many workmen come to the hanging-on place, and it is best that the air should be as fresh as possible at that point.

But, with a blowing machine, the top of the downcast must be covered; if, therefore, this shaft is the downcast there must be some special arrangement for *closing its mouth* so as to satisfy the conditions of ventilation, whereas, on the other hand, the service of winding requires it *to be open.* Several contrivances, which are well known, permit of these two conditions being satisfied at the same time, although they appear to be incompatible.

Thus, for example, the top of the pit may be terminated by two air-tight compartments, like locks, in which the cages with their suspending chains fit closely. These chambers are closed by two doors, between which there is a hole through which the rope passes. When the ascending cage has entered the corresponding chamber, the doors of that chamber are opened to let it come to the surface, and this operation closes at the same instant two other doors, which are at the bottom of the chamber and under the cage. The mouth of the shaft is thus always closed except during the very short interval when the doors are being opened and shut. We might even avoid the loss of air which takes place during this operation, by giving the cage so little play that it would form a kind of piston in the chamber.

It would be a still simpler matter to keep a shaft closed in which pumps or a man-engine were at work, because the cover at the mouth could remain permanently shut, and leave only an opening large enough for the rods to work through.

Nevertheless, these arrangements are always inconvenient, and we may say that it is *more simple* to have the shaft at which the ventilating machine works, entirely free from other mechanical appliances. Under these conditions an exhausting machine, placed on a shaft at the extreme rise of the workings, gives much better results than a blowing machine, which would have to force the air down to the hanging-on place, and would, therefore, often have to be placed on the top of the winding or pumping shaft.

On the other hand, we may say, in concluding, that, when a great explosion occurs, it is generally at some point where the air has become foul with passing through the workings. This point will, as a rule, be nearer the upcast than the downcast shaft; and, consequently, if the effects of the explosion extend as far as the surface, there is more danger of the ventilating machine being injured if it is at the top of the upcast than on the downcast.

(573) We see, from what precedes, that important arguments can be brought forward in support of both systems.

In actual practice the exhausting system is preferred as a rule, the fact of its facilitating the service of winding being considered to give it decided advantage over the other.

Besides, most exhausting machines can be made blowing machines at pleasure if, after the occurrence of an accident, it is found expedient to reverse the current for the purpose of saving life.

Again, for the purpose of keeping them out of harm's way in the event of an explosion, they need not be situated directly over the mouth of the shaft, but may be placed at some distance on one side, and connected with the shaft by a horizontal gallery under the surface. The pit itself can be covered with a light cap or brattice, which an explosion would easily lift before the pressure made itself felt laterally in the gallery connected with the ventilator.

Lastly, it is as well to be provided for an accidental stoppage of the ventilating machine. According to the construction of the machine, the current will either be *immediately* stopped, or it may

continue to flow, although in a *feeble manner*, through the interior of the ventilator.

All machines which act like pumps belong to the first category; and all those that act like turbines, driving the air before them by means of suitably-arranged *vanes*, come into the second category.

Arrangements can be made with any of these machines, and ought to be made with those of the first category, to have a kind of safety apparatus attached to them like that proposed by M. Devaux, whereby a large opening is made at the instant of their stoppage, so that the air can continue to flow.

This opening, which may either be the top of the shaft, or a special opening in the side gallery, can be closed with a great bell like a gasometer standing in a water joint.

This bell is partly balanced by means of a counterpoise, but only to such an extent that it requires the aid of the manometrical depression produced by the exhausting machine to hold it in its place. When the machine stops *the depression* vanishes; it is instantly replaced by *a compression* due to the inertia of the mass of air moving in the mine. The bell is raised and held in its new position by the balance-weight; and the current of air, stopped for an instant, is restored, and now passes through the new opening.

M. Devaux's arrangement can be combined with another, which is intended to assist the current which has re-established itself after the accidental stoppage of the machine.

It consists in having a pipe in the up-cast shaft descending to the bottom, by means of which steam from the boilers can be sent down to the point at which the return air enters the shaft.

The steam jet produced in this way heats the return air, and produces an effect similar to that of a furnace. This can be continued by firing the boilers until the ventilating machine has been repaired and set to work again.

This arrangement is only applicable with an exhausting machine; or, at any rate, it could not be used with a blowing machine unless the upcast shaft were near enough to the downcast for the boilers of the blowing machine, placed near the latter, to supply steam to the bottom of the former.

(574) All blowing and exhausting machines, and, in general, every means that can be imagined for setting in motion and displacing large masses of gas, can be applied to the purposes of ventilation; but it is necessary, in making a choice, to have regard to the special conditions which the machines have to fulfil in this particular application.

If they are compared with the blowing machines of blast furnaces, for instance, it is obvious that they have to displace *much larger* quantities of air, and that this displacement requires *much feebler* compression or expansion measured by the heights of the water-gauge. In the blowing engines of blast furnaces the object is to compress a limited mass of air under a sufficiently great pressure to assure a high velocity in the tuyers; in a mine, on the other hand, we desire simply to displace a large volume of air without giving it a higher velocity than that which is necessary in order to make it pass through a gallery of a given section.

A blowing engine for blast furnaces in which coke is used, is already considered large if it supplies 4,200 cubic feet of air per minute (2 cubic metres per second); the pressure in the reservoir may reach 8 inches (20 centimetres) of mercury or more, and the corresponding velocity of discharge 650 feet (200 metres) per second. (*Cours de Machines*, No. 372.)

A mine, on the other hand, will require 20,000, 40,000 or 60,000 cubic feet of air per minute (10, 20, 30 cubic metres per second) in order to be well ventilated, and the corresponding manometrical depression, which is not under the control of the engineer, but dependent on the resistances the air meets with in the workings, will not exceed a few inches of water, and is nearly always less than six inches.

Thus we could give an idea of the two kinds of machines by saying, that the ventilating machines of an extensive mine compared with the blowing engine of blast furnaces may have to displace *ten or fifteen times more air* with a manometrical depression *fifteen or twenty times smaller.*

We have here then very dissimilar characteristics, demanding machines of essentially different types.

Thus it may be said that, at the present day, *ventilating machines*

of the type usually adopted for the blowing engine are no longer erected.

The employment of pistons and valves presents serious difficulties, and is very disadvantageous as regards the motive power required.

The difficulties lie principally in the great dimensions which the cylinders require to have; so great indeed, that the pistons cannot be driven except at a comparatively low speed.

The unfavourable results afforded by these machines are due to two causes. In the first place the feeble manometrical depressions may become equal to or comparable with that which is required to open and keep open the exhausting or the discharging valves. If a depression measured by a column of water h is required to open the exhausting valves and an excess of pressure h' to open the discharging valves, and if h'' is the depression observed in the gallery leading to the machine, then the work which the machine has to perform for the *useful depression* h'' has the total depression $h + h' + h''$ for one of its factors.

The quantities h and h' may be diminished somewhat by balancing the valves or by placing them in a nearly vertical position, as is done in the case of blowing engines.

But even with these arrangements there still remains an important cause of loss of power in the friction of the periphery of the piston on the internal surface of the cylinder. This resistance, which is necessary in order to make the piston air-tight, cannot be neglected when we are dealing with these very low pressures.

Nevertheless, these piston and valve machines cannot be omitted from our enumeration of the machines which have been proposed or applied to the purposes of ventilation, although, in our opinion, they possess only a *kind of historical interest* in presence of the large volumes of air which have to be employed nowadays in extensive mines with large outputs.

(575) The enumeration of ventilating machines includes:

1. Those we have just referred to with valves as a general characteristic, whether of the bell or gasometer type, or those known as Hartz machines, or the piston machines.

They are distinguishable by this circumstance, that the movement of a diaphragm alternately increases or diminishes the capacity of a closed space; an exhausting process takes place while its capacity is being augmented, and a compressing process, immediately followed by the expulsion of the air, is produced when its volume diminishes. The exhaustion and expulsion take place with the concurrent movement of valves opening in the required sense.

2. The machines which are known more especially by the name of fans. They act by the motion of certain surfaces which drive the air before them, and thus produce a current in the required direction.

Of this kind are all the centrifugal ventilating machines, either with straight or curved vanes. They draw in air at their centre, throw it out at their periphery, either directly into the atmosphere, or into a chamber provided with suitably-arranged openings, which surrounds them. Such also are the ventilator with windmill vanes of M. Lesoinne, the screw of M. Motte, the screw fan of M. Pasquet, &c. &c. All these machines possess the common characteristic of not having an air-tight joint between the space from which they receive the air and the atmosphere into which they discharge it. They can produce only limited manometrical depressions; and they are subject to an irregular re-entrance of the air when the ventilation of the mine requires, under ordinary circumstances, a great manometrical depression, or when it happens to require it accidentally after a serious explosion, for example, which has produced falls of the roof. These machines may thus fail at the very moment when their utmost efficiency is required.

3. *Air-machines* in general, which act according to the same principles as the machines of the first class, in so far that they present a variable capacity which is placed alternately in communication with the space to be ventilated and the atmosphere; but differ from them in this respect, that the communications are effected by the rotation of certain pieces, and not by the play of valves.

These machines bear the same relation to those with valves as ordinary steam-engines, or pumps with pistons, bear to rotatory

steam-engines and rotatory pumps other than those which act by centrifugal power.

They are superior to the first class, inasmuch as they have no valves, and are free from the friction of a piston, and they have the advantage over the second class in forcibly extracting a determined volume of air at each revolution, independently of the more or less considerable manometrical depression which *the actual state of the mine* may require. It is only necessary to employ more power, and to be prepared for a little more escape of air if a greater degree of vacuum is necessary; whilst, with machines of the second class, this considerable depression *could not be produced*, and an increase of speed would, consequently, be without the desired effect.

Figures 449 to 466 represent a number of ventilating machines, for the study of which it will be necessary to turn to the explanation of the plates; and we shall confine ourselves here to the description of three of them, which are almost the only ones employed at the present day. These are:

The centrifugal ventilator or *fan*, with its latest modifications, some of which are due to M. Guibal, and others to MM. Kraff and Harzé. This machine belongs to the second class.

The pneumatic wheel of M. Fabry, and the pneumatic drum of M. Lemielle, which belong to the third class.

(576) The *centrifugal ventilator* or *fan*. This ventilator, as it is applied in mines, does not differ at all in principle from the contrivances of the same name that have been long known in foundries and workshops, and serve to blow cupolas and forges.

It consists essentially of a shaft provided with a certain number of vanes which are revolved more or less rapidly. The vanes revolve with as little play as possible between two sides, which are flat and usually parallel. The air is exhausted at the centre of the machine through a circular opening in one of the sides; it becomes entangled with the blades, is drawn round in their circular motion, and thrown out at the periphery by the centrifugal force developed in this way.

Such a machine is an exhausting one if the central opening

communicates with the interior of the mine, while the circumferences of the vanes are in contact with the outside atmosphere.

It is a blowing machine, on the contrary, when the central opening communicates with the outside air, while the vanes are surrounded by a kind of drum communicating at one part of its circumference with a pipe, which conducts the air to the desired point.

Blowing machines or hand-fans, in every respect similar to those used in foundries and smitheries, are employed in mines for the purpose of ventilating working places which are off the track of the air-current.

Large machines, which are employed for ventilating the entire workings of a mine, are usually exhausting in their action, although they may be so arranged, if thought necessary, in such a manner as to be converted into blowing machines in the event of this becoming desirable in consequence of some accident.

These machines have undergone successive modifications for the last thirty years; some in regard to their mode of acting on the air, others affecting the details of their construction.

At the present day they are light and strong machines, which, *under favourable circumstances*—that is to say, when it is not necessary to have great manometrical depressions—can produce the circulation of larger volumes of air than any other known kinds of mechanical appliances, and comparable to the amount of air obtained with furnaces in the North of England. But it is difficult or well-nigh impossible to make a calculation *à priori* of the quantity of air which a machine of given dimensions and revolving at a known rate will produce. The reason of this is that the manometrical depression required to produce the circulation of a certain volume of air depends upon the individual circumstances of the mine, and *is not one of the known data of the question.*

It is easy, again, to understand that an apparatus of this kind must be made to revolve at high velocities in order to produce considerable manometrical depressions; and if, from this point of view, its powers are less limited than those of furnaces, they are nevertheless more limited than those of the machines which will be described hereafter.

The kinds of machines which we are discussing are those which best suit the requirements of mines in which the necessary volume of air can be made to circulate without very great manometrical depressions; that is to say, those mines in which the workings are not very largely developed, or, if they are so developed, they have the compensating advantage of possessing large substantial air-ways or a suitable subdivision of the air-current.

These machines are unsuitable where the air-ways are small, insecure, and liable to be choked with falls. To sum up, we would say that the proper place of these machines would be to replace furnaces in mines in which the ventilation is *more difficult* than in the majority of those of the Newcastle coal-field, or for the purpose of replacing other machines in mines which are more easily ventilated than many of those of the North of France and Belgium, in which the seams are thin and fiery and lie between a weak roof and floor.

(577) The first exhausting ventilators which were employed in mining operations consisted simply of several flat vanes inclined to the radius either at a certain fixed angle, or so that the angle could be varied at pleasure, the amount being regulated by experiment. They were entirely open at their circumference.

M. Combes made the first scientific experiments with these machines. He employed curved vanes arranged like those of a turbine, and he sought to reduce the absolute velocity of the air at its point of discharge. This velocity is the resultant of the relative velocity of the air on the vanes at the point of discharge, and the absolute velocity of the vanes themselves at the same point, and it will be consequently *nil* if these two components are nearly equal and acting in opposite directions. M. Combes employed only a small number of vanes, and he left them entirely open at the circumference.

In this state of affairs the improvement was almost imperceptible, and it could not be otherwise, because Combes did not grapple with the *principal and essential* vice of these exhausting machines, which was the open circumference.

This defect was first pointed out by M. Letoret, who perceived

that the duty of any given machine of this kind was increased when it was surrounded by a circular envelope, and that the increase of duty augmented up to a certain point as the envelope enclosed a greater portion of the circumference. This result, which might appear to be paradoxical, in so far as it seems to point to an increase of useful effect by stopping up the very opening through which the air escapes, is due simply to the small number of vanes with which the machine was provided. The air did not escape in an unbroken mass between any two consecutive vanes. Whilst one of the vanes drove a body of air in front of one of its faces and expelled it from the machine, a vacuum was formed on its other face, and gave rise to re-entrances of air. From this arose irregular movements and eddies, similar to those which occur in a badly-constructed turbine, working under water, which has its channels only partly filled with water, owing to the insufficient supply from above. (*Cours de Machines*, Nos. 212 *et seq.*)

The existence of these eddies was easily demonstrated by simply throwing a handful of small pieces of paper against the circumference. The scraps of paper immediately underwent the most varied movements; some of them were projected outwards by the jet of air driven in front of the vanes, while others were drawn inwards by the vacuum on their posterior faces. In fine, the machine appeared to be mostly employed in creating vortices in the air round about its circumference, rather than in causing the air in its interior to be expelled to its exterior.

The remedy for this state of affairs is found in the circular envelope or casing which was first employed by M. Letoret, and afterwards perfected by M. Guibal.

The theory of the casing can be easily explained. Its object is to isolate the machine from the mass of air which surrounds it, and thus to avoid the irregular re-entrances of air. It is necessary that the outlet of the envelope be of the smallest section compatible with the volume of air to be delivered, and the velocity with which it is ejected, so that the current may be uniform at every point of its section, and, consequently, that there may be no return current. It was with this object in view that M. Guibal completed the casing of his fan by the addition of a movable

shutter, which can be placed in the most suitable position; that is to say, in that position which gives the *maximum opening*, beyond which the air would begin to re-enter intermittently after the passage of each vane.

But this is not all. The air expelled in this manner possesses an absolute velocity which may be regarded as the resultant of the tangential velocity which the molecules of air possess when they are moving inside the envelope, and of the small radial velocity which they acquire in proportion as the air becomes compressed under the influence of the centrifugal force in its passage from the centre to the circumference.

This absolute velocity corresponds to a certain loss of work, if the air which possesses it is thrown directly into the atmosphere.

This loss may be at least partly avoided, if the machine is so arranged that the air escaping from the envelope enters a channel, which is at first of about the same section as the air-current, and then gradually widens until its area is four or five times as great at the point where it terminates.

A conically diverging stack, or trumpet-shaped chimney, as M. Guibal calls it, reduces the velocity to about the fourth or fifth, and the momentum to the sixteenth or twenty-fifth of their original values.

The reduction is in reality *somewhat less* than this, because it is accompanied by a slight increase of pressure, which reduces the volume and augments the velocity. Inasmuch as the final pressure at the point where the air leaves the chimney is the same as that of the atmosphere, we see that the effect of the arrangement is to reduce the pressure in front of the shutter, which is evidently favourable to the action of the vanes. We thus see that the momentum which the air possesses as it leaves the envelope, instead of being lost, as one might expect, can be utilized to increase the useful effect, although indirectly. The ventilator in its most perfect form is represented by figures 460 and 461. It will be observed that the vanes have not the curved form which M. Combes was induced to give them from theoretical considerations. It is no longer a question of giving the molecules of air an absolutely inappreciable velocity at the moment they

leave the machine; with an envelope of a certain size this velocity cannot be *nil*; but it does not require to be so with the trumpet-shaped chimney of which we have spoken. It can be practically regarded as differing very little from the velocity of the vanes themselves at their exterior edges.

Machines constructed in the manner described above have been made as large as 30 feet (9 metres) in diameter, and 13 feet (4 metres) in width.* With these dimensions, and turning at the rate of 100 revolutions per minute, they can deliver as much as from 170,000 to 210,000 cubic feet of air per minute (80 to 100 cubic metres per second) in mines where a depression of the water-gauge of 1 to 1½ inch (3 to 4 centimetres) is sufficient, such as those in the North of England. It is also possible with these machines to produce a depression equal to a column of water of 2, 3, or even 4 inches (6, 8, or 10 centimetres) in height. But with a given machine driven at a given speed, the quantity of air decreases in proportion as the exigencies of the mine require a greater depression of the water-gauge, and the opening left by the shutter has to be reduced at the same time.

Experiments have shown that, when the machine is working under favourable conditions, there is little variation in the ratio of the volume generated by the vanes and that delivered by the machine. We may fairly assume this ratio to have a mean value of 2·75, with a tendency to vary between narrow limits inversely to the variation of velocity at which the machine is driven. This purely empirical result can be employed in making an approximate calculation of the dimensions of a machine which has to be put up at any mine; but these dimensions cannot be accurately determined, as we have already pointed out, because one of the principal elements of the calculation cannot be ascertained *à priori*; namely, *the depression of the water-gauge corresponding to the delivery of a given volume of air*, since that quantity varies according to the circumstances under which the air circulates in the mine.

We cannot, therefore, proceed except by analogy, and by a summary comparison between the mine with which we are

* Some have been made 36 and 40 feet in diameter in England.—*Translators.*

occupied and some other mines, for which we already possess this datum from actual observation.

(578) The principal advantages of M. Guibal's machine can be obtained by arrangements of a different kind from those employed by that engineer.

These arrangements have been specified by M. Harzé, who took for his original model the machine which had been put up to ventilate the works of the Mont Cenis Tunnel. M. Harzé's ventilator has its axis vertical, which enables it to be conveniently placed above the mouth of the up-cast shaft. But this arrangement is not what characterizes the machine, and constitutes its essential difference from M. Guibal's.

The true difference consists in suppressing the envelope, which is essential to M. Guibal's machine, and in substituting for the diverging conical chimney a particular apparatus which surrounds the whole machine, and has been named the *diffuser* by the inventor.

By suppressing the envelope we get rid of the loss of work due to the friction of the air carried round by the rotation of the vanes. But this loss is perhaps compensated, or more than compensated, by that due to the relative movement on the vanes, which are much more numerous than in M. Guibal's machine. Besides, we have a right to assume that, as the air can escape directly all round the circumference, the machine is not so well qualified to produce so great a manometrical depression as if it had an envelope.

It is necessary also to arrange matters so that, in spite of the absence of the envelope, re-entrances of air cannot take place behind the vanes. This has been done by increasing their number sufficiently, as we have already said, and besides, if necessary, by reducing their height in proportion as they are situated further from the centre. This arrangement has already been adopted in certain ventilators which have been constructed in England, and are known by the name of Brunton's ventilators.

In this manner it may be so arranged that each outlet for the air has only a limited sectional area, and that the sum of the areas of

the whole of the outlets present an area comparable to that which is regulated by the shutter in M. Guibal's machine. This is a somewhat delicate task; for it is important, almost in the same degree, that the section should not be large enough to permit of re-entrances of air, nor too small to create a useless obstruction to the free escape of the ventilating current. In this respect the regulating shutter of M. Guibal's apparatus is a simple means which is wanting in M. Harzé's fans.

The diffuser consists of a series of fixed directing plates, which form channels in which the air leaving the ventilator should begin to flow in parallel planes in virtue of its absolute velocity. These plates are so arranged that the section of each channel formed between them goes on increasing from the inside circumference until it reaches the outside circumference of the diffuser.

The arrangement of moving vanes in the ventilator, and fixed directing plates in the diffuser, employed by M. Harzé, will be seen by referring to figure 462. The vanes are not curved backwards at the circumference in the contrary sense to the direction in which they move, like the vanes of turbines, and as M. Combes proposed to make those of his own ventilator. This curvature, the object of which is to deprive the escaping air, as much as possible, of its absolute velocity, and give it a relative velocity in the opposite sense to that in which it is carried, has not been found *efficacious* in M. Combes' ventilator, at least when it is worked at a high speed; and it is *useless* with the diffuser, playing the same part as the conical chimney of M. Guibal's machine, since the velocity of escape in that case is not lost. From a *theoretical* point of view, we can, therefore, give the vanes any direction we please at the outlets.

When we come to the directing plates, the condition that they receive the air from the ventilator without shock demands that they be placed in an almost tangential position to the absolute velocity of the air, which is itself the resultant of the relative velocity on the vanes and the velocity of the vanes themselves. The smaller the depressions of the water-gauge, and the greater the velocity of the machine, so much the less important will the first component be in comparison to the second, and so much the

more will the first particles of the current approach the position of tangents to the inner circumference of the diffuser. At the outside of the diffuser, on the other hand, the condition of having the smallest velocity, and, consequently, the largest outlet, demands that the directing plates be placed nearly at right angles to the external circumference.

Such are the considerations which ought to regulate the general design of these machines. They are certainly very ingenious, and can be applied with much advantage wherever the depressions of the water-gauge are small, such as 1 or 1½ inch. (For the complete theory of these machines, consult the interesting paper of M. Harzé, published in 1870, and inserted in the *Revue Universelle de Liége.*)

(579) The machine known by the name of the pneumatic wheel, or Fabry's ventilator, is not capable of producing volumes of air at all comparable to those delivered by the large centrifugal ventilators working with small manometrical depressions, because it is not practicable either to construct it sufficiently large, or to drive it sufficiently fast. But it is essentially distinguished from these machines by the fact that the volume of air which it extracts from the mine at each revolution is always *perfectly determined and independent* of the manometrical depression, except in as far as this depression has an influence upon the leakages. The result is that the machine gives the same volume of air at every mine where it is established, save that it works at different depressions which vary in different mines. The power of the engine of the ventilator ought to be proportioned to these depressions, and this result is obtained in practice by providing it with variable expansion gear.

A further result, and one of great importance, is that in the case of an accident, such as the occurrence of falls of roof, due perhaps to an explosion of fire-damp, which might render the ventilation very difficult for a short time, this machine will always continue to give the same volume of air at each revolution, *provided it continues to revolve*, even if it were necessary to double, treble, or still further increase the normal depression. In a similar case another venti-

lator could not produce such a depression, and the ventilation would be stopped, or, at all events, rendered feeble at the very moment when it might be of the utmost importance to have it as perfect as possible. (See No. 575.)

Figure 463 represents the theoretical arrangements of this machine, and the principal details of its geometrical outline.

The apparatus consists, in reality, of two wheels of equal diameter, and each provided with three epicycloidal teeth, two of which are always in contact. The teeth are so arranged that they meet *regularly;* that is to say, during an entire revolution of the wheels two of the teeth are always in contact either on one side or the other of the line which joins their centres.

The wheels turn in the sense indicated by the arrows in producing an exhausting action; it is only necessary, however, to reverse their motion in order to produce a blowing action.

The exhausting or blowing action takes places in a rectangular chamber, which communicates with the workings to be ventilated. The dimensions of this chamber are determined by the distance between the centres of the two wheels on the one hand, and by their width on the other. The teeth are merely simple epicycloidal surfaces which come into exact juxtaposition without exercising any pressure upon each other. The shafts, which bear these two wheels, are connected together by two ordinary toothed wheels having the same circumference. The three teeth of each wheel of the ventilator have an arc of 60° each for their base on the circumference. Their epicycloidal portions are connected to a median vane or blade projecting beyond their circumference, and moving in a circular part of the envelope which commences at the lowest point of the wheel, and embraces an arc of 120°.

The sides of the space within which the two wheels move are vertical, and extend at least as far as the limits shown by the letters $x\ y\ z\ z'\ y'\ x'$. (See the figure.)

It is evident from the figure that at the instant when the portions m and m' of the teeth A and A′ cease to be in gear after having passed the line of the centres, the portion n' of the tooth A′ comes into contact on the other side of this line with the part n of the tooth B. The two surfaces n and n' remain in contact during a

sixth part of a revolution, until the vane B is upon the line joining the centres, and then the two surfaces p and p' of the teeth B and B′ come into contact in their turn.

We thus see that there is never a free communication from the interior to the exterior *between the two wheels;* we see also that at the instant when two teeth come into contact, *a volume of the external air* corresponding to the area of the perimeter O a b c d e g f g h O, which hardly differs from the sector O a e h O, is enclosed by them, and at the next instant this volume of air is placed in communication with *the internal air.* The total quantity of air which re-enters during a complete turn is measured by the total surface of the two primitive circumferences augmented by six times the area of the four small triangles $a\,b\,c$, $c\,d\,e$, $e\,f\,g$, $f\,g\,h$. On the other hand, each time that the vane of one of the teeth comes within the casing corresponding to it, *a volume of internal air* corresponding to the surface of a sector of 120° in a circumference equal to that of the casing, is enclosed by it, and at the next instant this volume of air is placed in communication *with the exterior.* We infer from this that during one entire revolution, *the excess of air discharged from the machine over that which re-enters,* neglecting the areas of the small triangles referred to above, is measured *by the two annular areas comprised between the circumferences of the casings and the circumferences of the primitive wheels.*

(580) If, therefore, we designate by R and r the radii of these two circumferences, and by L the width of the machine, the volume of air extracted by a number of turns n will be approximately

$$V = 2n\pi\,(R^2 - r^2)\,L.$$

It is evident that when r is given the quantity R is not altogether arbitrary; it is determined by the condition that the vanes of one wheel must not be long enough to come into contact with the teeth of the other wheel. It is easy to see, by referring to the figure, that if both wheels were moved backwards through an arc of 30°, the point c would return to the point a at the same time that the vane of the tooth A′ came into the position O′a, tangential to the wheel

O. The radius R cannot, therefore, be greater than the length $O'a$, which is equal to $\sqrt{4r^2 - r^2} = r\sqrt{3}$.

We may, therefore, put $R \overline{\overline{<}} r\sqrt{3}$.

When we introduce the equation $R = r\sqrt{3}$, the above formula becomes:

$$V = 2n\pi (3r^2 - r^2) = 4n\pi r^2 L.$$

It is necessary to make some corrections by taking into account the small triangles with curved and straight lines, which we have neglected until now.

The sum of these four small triangles is evidently equal, by reason of their symmetry, to twice the area of a curvilinear triangle such as $c\ e\ c_1$; and the latter, which approaches the form of a rectilinear triangle, is similar to the triangle $c\ o\ e$, whose three sides are respectively perpendicular to its own. But the latter is an isosceles triangle, having an angle of 30° at its apex. On the other hand, the triangle $c\ e\ c_1$ has evidently one-half the side of the inscribed hexagon for its height, or $\frac{1}{2} r$, and its area is consequently $\frac{1}{2} r \times \frac{1}{2} r$ tan. 15° $= \frac{1}{4} r^2$ tan. 15°.

The corrected volume is thus:

$$\begin{aligned} V &= n \times 4\pi r^2 L - n \times 12 \times \tfrac{1}{4} r^2 \tan. 15^\circ \times L \\ &= nr^2 L\,(4\pi - 3 \tan. 15^\circ) \\ &= nr^2 L\,(12 \cdot 5664 - 0 \cdot 8024) = 11 \cdot 764 \times nr^2 L. \end{aligned}$$

This is the maximum theoretical volume, without taking leakages into account, and supposing that the vanes are made as large as they can possibly be.

In the greater number of ventilators of this kind $r = 1^m$ (3·28 feet) $L = 2^m$ (6·56 feet), and one revolution produces therefore a volume of air equal to $2 \times 11{\cdot}764 = 23{\cdot}528$ cubic metres ($3{\cdot}28^2 \times 6{\cdot}56 \times 11{\cdot}764 = 830$ cubic feet).

If we suppose a velocity of thirty revolutions per minute, or half a revolution per second, which is rarely if ever exceeded, we shall have an apparatus capable of delivering a theoretical volume of 11·764 cubic metres (415 cubic feet) per second, or practically about 10 cubic metres (350 cubic feet).

If L were made 3^m (9·84 feet), the volume would become 15 cubic metres (525 cubic feet).

According to the dimensions and speed usually adopted, Fabry's ventilator can thus produce a ventilation of 10 to 15 cubic metres (350 to 500 cubic feet) per second.

This is much less than the volume produced by centrifugal ventilators, or furnaces, where they can be applied. But these volumes are sufficient for the wants of many mines as far as their *quantity* is concerned; and they can be obtained at *any manometrical depressions whatever*, a result which is not attainable by the use of either furnaces or the other ventilators.

(**581**) Lemielle's ventilator is of more recent design than Fabry's, and it can be constructed of dimensions which admit of a *much larger volume* of air being produced.

It possesses the same property of producing as great depressions as may be desirable; but it is more complicated, and is more liable to leakages.

Notwithstanding certain practical objections, however, which result from its more complicated construction, and the greater care required to keep its various parts in good repair, it seems to be coming more into use. It is suitable for those mines which require a *manometrical depression*, either present or prospective, such as ordinary ventilators or furnaces cannot produce, and at the same time a greater *volume of air* than can be obtained by means of Fabry's ventilator, under the conditions of capacity and velocity which have been accepted in practice.

After having passed through various modifications, Lemielle's ventilator, according to the present mode of construction, consists of a hexagonal prismatic drum (*fig.* 464), or circular cylinder, movable about a vertical axis O′ to which three shutters or wings, A B, A′ B′, A″ B″, are connected by means of hinges placed at intervals of 120° on three generatrices. The outer edge of each of these wings is joined to two connecting rods, which turn round the centre O in such a way that, taking any one of the wings, such as A B, the hinge A moves on the circumference of the circle O′, and the edge B on the circumference of the circle O. As a consequence the wing A B is at one point of its course almost tangential to the circumference O′, and at other points it forms a larger or smaller

angle with that circumference. The circumference O being the periphery of a stationary cylinder, in which the apparatus moves, the shutter occupies the whole interval between the side of the outer cylinder and the moveable drum, in whatever position the latter may be placed, and in this way it separates the space *in front of its face* from that which is *behind its back*. The volume of the space enclosed between two consecutive wings or shutters A B, A′ B′ enlarges whilst the wings are unfolding from the drum as it turns in the sense A A′ A″; and it decreases when the wings are being drawn in again. When the space is increasing it is placed in communication with the interior of the mine, and produces an effect of aspiration on the air contained in it; but when it has reached its maximum, the next following wing intercepts the communication with the interior at *b* at the same moment that the space is placed in communication with the outside at *b′* in order to allow the air to escape. Such is the simple principle on which these machines work. It will be remarked that the connecting rods, which determine the relative movements of the wings on the drum, have their centre in the *interior* of the movable drum, and that their extremities are connected to points on the *exterior* of the same drum. It should be understood therefore that there are longitudinal slits suitably placed on the surface of the drum, through which the rods work, and that arrangements are made to hinder the escape of air as much as possible. These details are shown in figure 464, to the description of which we must refer the reader.

A calculation of the volume of air expelled can be made with the assistance of graphical representations, when the radius of the drum and outer cylinder, and the degree of eccentricity and length of the wings, are given.

By a careful study of the graphical representation of the apparatus, we can find the best points at which to place the inlet and outlet orifices, for the dimensions that may be adopted in any particular case, so as to obtain the maximum useful volume of air, or, in other words, the maximum difference between the *expelled volume* and the *volume that re-enters* during each interval of 120° when the same phase of the system is repeated. Having

made this calculation with given dimensions, and obtained a certain volume, we shall find, if we change the scale of the figure and the height of the outer cylinder, that the volume will vary proportionally to the product of the square of the homologous horizontal dimensions multiplied by the height.

The largest machines of this kind which have been hitherto constructed have a diameter of 14 feet ($4^{m}{\cdot}30$) for the outer cylinder, $8\frac{1}{2}$ feet ($2^{m}{\cdot}60$) for the drum, and a height of 23 feet (7 metres). With these dimensions, and revolving at a rate of 22 revolutions per minute, they are able to produce a volume of air equal to 63,570 cubic feet per minute (30 cubic metres per second) when they are in a perfect state of repair and of good construction.

In machines of these dimensions provision has to be made to prevent the torsion of the drum, which is driven from its upper end only, and the warping of the vanes, whose hinges are influenced by this torsion; and for this purpose it is best to construct the drum of sheet iron.

The large volume of 63,000 cubic feet of air per minute, and the possibility of working it at great manometrical depressions, render this machine applicable in some cases in which Fabry's machine would be inadequate as regards the *quantity of air produced*, and Guibal's *as regards the manometrical depression which might be normally or accidentally necessary.*

Lemielle's machine responds to the exigencies of extensive mines having a large output and a difficult ventilation owing to the small dimensions of the galleries.

Figures 465 and 466, for an explanation of which we refer to the description of the plates, give the principal details of construction of the machine; but figure 464, on the other hand, is only a theoretical diagram.

(582) The three foregoing machines (Nos. 576 to 581) are almost the only ones that are put up at the present day.

They can evidently be set in motion by any kind of steam-engine, but the question of the choice of a motor gives rise to several observations.

In the case of ventilators which revolve at a more or less rapid

speed, like those which depend upon centrifugal force, we can very well attach the motor directly to the shaft of the ventilator, so long as the speed does not exceed 30, 40, or even 50 revolutions per minute; but when the speed amounts to 60, 80, or 100 revolutions and more (a state of affairs that may arise when somewhat considerable manometrical depressions are required), it appears preferable to employ an intermediate means of transmission of power, and this will usually consist of two pulleys of unequal diameter connected by means of a belt. The larger pulley will be on the fly-wheel shaft of the engine, and the smaller on the shaft of the ventilator. The fly-wheel of the engine might itself be employed, instead of having a separate pulley on the same shaft.

It is not that velocities of 100 revolutions and more cannot be obtained directly from steam engines; but when these machines are driven at high velocities they require to be constructed both very exactly and substantially; and, as can be easily imagined, they require more frequent repairs and more care in keeping them in an efficient state than less rapidly moving machines. But ventilating machines are amongst the number of those which it is very important to keep going regularly, in order to avoid dangers which may sometimes be very great, and in any case stoppages, which are expensive. It is thus the interest of everyone to abstain from driving them with steam engines running at a high speed.

Fabry's machine cannot be driven faster than 30 revolutions per minute, at least with great manometrical depressions, if we would avoid vibrations of the blades, and the breakages to which they may give rise. The steam engines which drive them can, therefore, always be coupled to them directly. The arrangement proposed by M. Colson for winding engines (No. 444) is very suitable for this case; the two equal wheels which constitute the apparatus are then provided with two cranks, which always remain in symmetrical positions. The steam cylinder is vertical, and symmetrically situated in regard to the two wheels. The piston-rod carries a T-shaped piece of a length equal to the distance between the centres of the wheels, and having connecting-rods attached to its two extremities and working the two cranks

referred to above. This arrangement assures the vertical movement of the piston-rod, and enables us to dispense with the use of guides or parallel motion.

The velocity with which the vertical drum of Lemielle's machine revolves *is not greater than* the velocity of Fabry's apparatus, and in the case of large machines it is smaller, and does not exceed 20 to 25 revolutions per minute.

The natural arrangement of the steam engine in this case is to have a horizontal cylinder placed above the drum, and connected directly to a crank keyed on to its shaft. The same arrangement is also applicable to rotatory ventilators depending upon centrifugal force, which have their axes in a vertical position, so long as their velocity of rotation is not too great.

(583) The power required by the steam engines employed in driving these ventilators, depends partly upon the volume of the air which has to be passed through the mine, and partly upon the manometrical depression (which cannot be fixed *à priori*) which this amount of ventilation will require.

It is necessary therefore, in order to calculate the power required, *to make an hypothesis* as to the depression, which may vary from ¼ and ½ inch of a water-column, in easy cases, to 5 or 6 inches, and more in difficult cases. A nearer estimate cannot be made without comparing the mine with which we are engaged with others placed in a more or less analogous condition. But this comparison must always necessarily leave a vagueness about the question, which we can meet by adopting an engine with variable expansion, which enables us to alter the power of the machine that has been erected.

It is better, in general, to make a sufficient allowance in our calculations, and always to erect a machine or furnace with a considerable margin of power, in case it should become expedient at any time largely to increase its capabilities. We are thus in a position to make up for any error in the original estimate; and, furthermore, we can greatly increase the ventilation if it suddenly becomes necessary to do so, as would be the case, for example, during a

rapid fall of the barometer, or after an explosion of fire-damp, and so on.

If we know V, the volume of air required in cubic metres per second, and the manometrical depression, or the height of the column of water which serves to measure it, the corresponding theoretical work can be easily calculated if we refer to the results given in Nos. 334–337 of the *Cours de Machines*.

The theoretical formula is $Tm = P_1 V_1 l \frac{P_2}{P_1}$, which becomes in the first place $Tm = V_1 (P_2 - P_1)$, since the ratio $\frac{P_2}{P}$ is very little more than unity.

This equation may be written $Tm = V_1 \rho \frac{P_2 - P_1}{\rho_1}$, the quantity ρ_1 being arbitrary. If we take it equal to the weight of a cubic metre of water, the term $V_1 \rho_1$ will become the *weight in kilogrammes*, or the *volume in litres* of the quantity of air expressed in the first place in cubic metres; and the term $\frac{P_2 - P_1}{\rho_1}$ becomes the height of water which measures the difference of the pressures P_2 and P_1; that is to say, exactly the quantity h.

Moreover, since $\rho_1 = 1000$, the work sought is expressed by $Tm = 1000Vh$.

If we supposed *a very large ventilator*, for which $V = 75$ cubic metres per second (158,924 cubic feet per minute), and at the same time a very easy ventilation, for which a depression of 2 centimetres (·786 inch) sufficed, we should find $Tm = 1000 \times 75 \times 0{\cdot}02 =$ 1500 kilogrammetres, or 20 *chevaux-vapeur* ($Tm = 62{\cdot}5 \times \frac{\cdot 786}{12} \times 158{,}924 = 650{,}595$ foot-pounds, or 19·8 horse-power.)

With one of Fabry's machines producing a theoretical volume of 11·764 cubic metres per second (24,927 cubic feet per minute), and supposing a manometrical depression of 8 centimetres (3·15 inches), we should have:

$Tm = 1000 \times 11{\cdot}764 \times 0{\cdot}08 = 941$ kilogrammetres, or say 13 *chevaux-vapeur.*

($Tm = 62{\cdot}5 \times \frac{3{\cdot}15}{12} \times 24{,}927 = 408{,}958$ foot-pounds, or 12·39 horse-power.)

With a very large machine of Lemielle's design, which produces a theoretical volume of 30 cubic metres per second (63,569 cubic feet of air per minute) at a great depression amounting to $0^{m}\cdot15$ (5·905, or say 6 inches), we would have:

$$Tm = 1000 \times 30 \times 0^{m}\cdot15 = 4500 \text{ kilogrammetres, or 60 } \textit{chevaux-vapeur}.$$

$$(Tm = 62\cdot5 \times \frac{6}{12} \times 63{,}569 = 1{,}986{,}531 \text{ foot-pounds, or 60 horse-power.})$$

The three numbers given above enable us to form an idea of the very wide limits between which the power that has to be applied to produce ventilation is comprised. It is understood that we are here speaking only of the *theoretical expenditure.*

A large number of trials of the different machines have been made, especially in Belgium.

The manometrical depressions were observed directly, and the volume of air passing through the return air-ways was obtained by means of anemometrical measurements, and the corresponding work was deduced from these quantities with the aid of the foregoing formula. On the other hand, the work done by the steam engine was obtained by means of diagrams produced by Watt's indicator.

The ratio of the first quantity to the second is a fraction which measures what may be called the useful effect of the machine. The work lost includes the passive resistances of the ventilator, the transmitting gear, and the steam-engine, the losses due to escapes and re-entrances of air in the ventilator, and lastly, one-half of the momentum which the air possesses uselessly on its return to the surrounding atmosphere.

This ratio increases with the size of the machine; and it diminishes pretty rapidly when it is not in a thorough state of repair. It is greater for those machines which are driven at a medium velocity than for those that are driven rapidly. Thus, for example, it may even surpass 60 per cent. for a large Lemielle machine going at a slow rate. It may be 50 per cent. for a centrifugal ventilator with medium speed and manometrical depression, and it may fall to 40 per cent., or even lower, when the velocity or the depression becomes very great.

In practice we should adopt the amount of useful work which appears to be the most likely under the circumstances, then put up a machine of such dimensions as to enable us to obtain the work required while going with a moderate amount of expansion. We shall then be in a position to *increase* or *diminish* this work, according as our trials show it to be necessary, by *diminishing* or *increasing* the amount of expansion.

(**584**) The three machines described above (Nos. 576 *et seq.*), and those which are referred to in No. 575, and represented by the figures 449 to 466, are not the only ones which have been either tried or adopted in practice. There are others also, but we shall here merely enumerate the principal ones.

We shall mention here:

1st. The employment of a water-fall. This is an apparatus which consists of a vertical pipe slightly contracted just below its upper end, at which the water is admitted, and provided with small openings or *aspirators* immediately below the contraction, through which the air is drawn in and carried away by the current of water. Fig. 467, for an explanation of which we must refer the reader to the description of the plates, will give an idea of this kind of apparatus. It is not much employed nowadays, and gives only a low useful effect.

2nd. The Archimedean screw, or rather Dutch screw, placed horizontally in a cylinder, and filled with water to such a height that the lower edge of the shaft which carries the screw, is always immersed to a certain extent. By this contrivance the compartments, which are formed above the water by the spires of the helicoidal surface and the upper half of the cylinder, are isolated from each other, and a rotatory movement transmitted to the screw produces a motion of translation along the axis of the mass of air which fills these compartments. The air is then drawn in at one end of the screw and forced out at the other. This arrangement, which was proposed by M. Guibal, under the name of the hydro-pneumatic screw, appears to give rise to a very serious amount of friction, due to the movement of rotation of the screw in the water and to the movement of translation which is given to the water as

well as to the air along the axis of the canal. The hydro-pneumatic screw is represented in fig. 468.

3rd. The direct employment of steam *without the intervention of a steam-engine.* This application can be made in two ways:

We may, in the first place, look upon the steam as a *warm body* which mixes with the air, and heats it by imparting its own sensible heat to it. It thus acts in the same way as that part of an air-current which passes over a furnace, and is afterwards mixed with the general current in the upcast shaft at the point where the latter enters after it has traversed the workings.

It is easy to see that this mode of employing steam is *altogether defective* as regards economy of fuel. Its only advantage is the possibility of avoiding the employment of a furnace in the interior of the workings. The boilers can be placed at the surface, and the steam can then be carried down the shaft in pipes to the point at which the current of return air enters it.

It will be seen, in the first place, that, as compared with a furnace, we lose the whole of the heat which is carried into the chimney by the gases that have passed under the boiler, and this is often nearly one-half of the heat developed on the grate.

Besides this, the steam, which is liable to condense when it comes in contact with cold surfaces, will communicate a notable part of its heat to the sides of the shaft without a corresponding useful effect. This defect will be fatal in all shafts which are not perfectly dry.

Lastly, we must remark that the heat is very badly employed, *even in an ordinary ventilating furnace,* as compared with its effect when it is transformed into work by the intervention of a steam engine. In ventilating a mine, the question is not how to *heat,* but how to *displace* a certain volume of air; and when, after this displacement has been completed, the temperature of the air is sensibly higher, thereby indicating an expenditure of heat, this expenditure has produced no useful effect as far as the object we had in view is concerned.

The second manner of employing steam is to make it act *by the momentum* which it acquires when it escapes from the interior of a reservoir, in which it is confined at a higher pressure than

that of the surrounding atmosphere. It then acts under the same conditions as those which obtain in the blast-pipes, by means of which the draught of locomotives is produced. We have then essentially different conditions from those which obtain when the steam acts simply as a heating body. The momentum acquired by the steam corresponds to a certain moving force, and this momentum, in communicating itself to the surrounding air, can produce an effect comparable to that which would be obtained if this initial work had been directly applied to the air.

We thus approach the condition of an ordinary ventilating machine driven by a steam engine, and it is thus evident that the second method of employing steam directly is superior to the first.

We cannot see any reason, *à priori,* why the employment of steam in this way should not afford results comparable with those which are obtained with a high-pressure expansive steam engine without condensation. Perhaps it might even be said that this system would have the advantage, because we get rid of the passive resistances inherent to the working of the engine. But it would be necessary to make numerous experiments to see how the jets of steam should be arranged in order to obtain the movement of the whole current of air without eddies or return currents, and for the purpose of finding out what losses would occur through the heating of surrounding bodies, and of the body of the air itself, &c. &c.

In conclusion, this system, which has been known for a long time, and even tried, does not possess the defects attributed to it by most engineers, but, for want of having been sufficiently studied and experimented with, it has not, so far, been extensively applied in practice.

§ On the distribution of the air-current in a mine.

(585) In the preceding pages we have pointed out the numerous causes that are at work in altering the constitution of the air in a mine, and thereby making it indispensable to maintain a constant

current through workings that are in active operation. We have considered the circumstances under which this current can be established and continued spontaneously, without our having recourse to special artificial means. Lastly, we have seen what are the means we have at our disposal for producing the necessary current of air artificially, when natural ventilation will not operate at all, or only in an insufficient manner.

We shall now suppose that we have an air-current at our disposal, either natural or artificial, and it remains for us to examine what use we can make of it, or how we can best distribute it amongst the various parts of the mine in order to serve the object we have in view. That object, as we have seen before, is to keep the working places in a healthy state, and to avoid the various kinds of dangers that arise in the presence of accumulations of irrespirable or explosive gas, which may be given off in the whole of the working places or at certain points.

(586) The first question we now have to consider is, the quantity of air required to ventilate a given mine properly; and after that we can inquire how we are able to ascertain whether we get the requisite quantity or not, or, more generally, what is the quantity we really employ at any given instant.

The first question can hardly be answered exactly, because the elements upon which the reply ought to be based are very numerous, and cannot for the most part be submitted to an exact numerical computation.

We shall not have settled the question by counting the number of men and animals which are in the mine at the same time during a day's work, together with the lamps used for lighting purposes. The quantity of air which is *absolutely necessary* for them is quite *insignificant* as compared with that which is determined by other conditions than the simple obligation of preventing the air from becoming irrespirable for men, or unable to support the combustion of lamps. It is necessary for men who are working in it the whole day long, that the air should not differ appreciably from the normal condition of the atmosphere. It is thus necessary to circulate a large excess of air, for the purpose of renewing the oxygen

that has been absorbed, eliminating the carbonic acid that has taken its place, and diluting gases of every kind by so large a body of fresh air, that their proportion becomes very small or almost imperceptible.

The air is insufficient in quantity if the smell of organic exhalations or sulphuretted hydrogen can be perceived, if fire-damp shows visibly on the flame of a lamp, if the current is not rapid enough to cause eddies, and so assist the diffusion of the gases that are disengaged, &c.

The air-current ought usually to be sufficiently strong to deflect the flame of a lamp, or enable us to judge of its direction by simply turning the face towards it. On the other hand, the current ought not to be too rapid (say over 300 feet per minute, $1^{m}\cdot50$ per second), lest it become hurtful to the health of the miners who enter it in a state of perspiration, or in case it should become accidentally charged with gas, and come in contact with a safety lamp exposed too directly to its action.

Lastly, the quantity of air should increase with the quantity of gas given off in the mine, and that is in proportion to the extent of the fresh surfaces that are daily laid bare in the working-places, and, consequently, it has a very intimate connection with the daily output of the mine, &c.

Each of these considerations has its own value. They show that the quantity of air ought to be increased with the number of men, the section of the working places, and, above all, with the daily output; we shall also see that it ought to be increased in proportion as the mine is warmer, and the workings are more extensive, because, in the last case, there are more leakages through doors and stoppings, &c. &c.

But all this does not enable us to settle numerically the quantity of air that is necessary for a given mine. We cannot hope to fix upon a precise number by a mere process of reasoning; inasmuch as the circumstances of one mine are never identically the same as those of another, nor can they be, in the case of each mine, the subject of numerical calculation.

We shall only say, without attaching more importance to this means of estimating than it deserves, that, according to a recognized

rule-of-thumb method of estimating, it is said that the quantity of air passing through a coal mine ought to vary between 100 and 200 cubic feet per minute per ton of coal extracted daily (the number of *cubic metres* of air per second should vary from $\frac{1}{20}$ to $\frac{1}{10}$ of the number of tons of coal extracted). Thus, for example, a mine producing 300 tons of coal per day, and there are many larger outputs than this at the present day, would require somewhere between 30,000 and 60,000 cubic feet of air per minute (15 to 30 cubic metres per second); that is to say, *at least* as much as one of Fabry's largest machines could supply.

We repeat again, that this is a purely empirical rule, and it is also an unreliable one, since it takes into account only one of the numerous elements of the question.

Independently of the above considerations relative to the *quantity* of air, we ought also to take into account its *pressure*. It is easy to see that a great manometrical depression will give rise to losses through the doors and stowing, insomuch that, in order to have a certain useful volume of air at the extremity of the workings, it will be necessary to have an excess of air entering the mine. We conclude, therefore, that the power we must provide to effect the ventilation of any given mine increases very rapidly in proportion as the ventilation becomes more difficult, since the power required to produce *a given volume* is proportional to the depression, and since the volume must increase in proportion as *the depression is greater.*

This increase of the volume of the air, in connection with the increase of the depression, cannot be neglected. It is necessary to understand that the losses of air which occur during its passage between the downcast and upcast shafts are always considerable, and that they increase greatly with the depression of the water-gauge.

Air is a very subtle fluid, which can pass through the smallest crevices, and thus it is that a room which appears to be entirely air-tight is sufficiently ventilated, sometimes even more than is required, by the crevices at the doors and windows.

But a trap-door in a mine cannot be made or kept so air-tight as an ordinary door in a house, and it is necessary to open it very

frequently for the purpose of passing and repassing along the roadway. A stopping, again, is hardly ever quite air-tight, or if it happens to be so, there are sure to be leaks through the adjacent pillars, which are often more or less crushed and fissured. The blocks of stowing left behind the faces are less tight still.

Common experience testifies to the truth of these assertions. Thus, for example, at the end of a long drift, which serves a series of level-course working-places, we shall sometimes get only two-thirds, or even one-half, of the volume which is found at the entrance of the same gallery, or in the return air-way.

These losses should be provided against as much as possible by building the stoppings carefully, placing two, or even three, trap-doors at the same point, packing the gob-walls attentively, or having a space of a certain width in the middle of the stowing packed tightly with small coal from the holing, &c.

(587) After what has been said in the preceding pages, it is evident that it is often a matter of real advantage to be able to measure the quantity of air which we are able to dispose of at different points in the workings of a mine. This is usually done in the following way: A part of a gallery where the section is as uniform as possible for several yards of its length is chosen, and its section measured; the velocity of the air at various points in it is then determined, and the quantity of air is the product of the section multiplied by the velocity. No special remark need be made about measuring the section of the drift.

The measurement of the velocity of the air may be made in various ways, all more or less analogous in principle to the methods usually adopted in gauging streams of water.

We may, in the first place, measure a certain length of the gallery, supposing its section to be sufficiently uniform, and then observe the time occupied by the air in traversing it from one extremity to the other. For this purpose we may set fire to a small quantity of powder at a given instant, or throw some drops of a volatile and strong-smelling liquid into the air-current at one end of the measured part of the air-way, and the observer placed

at the other end of it notes the time at which he first perceives the powder smoke or the smell of the vapour.

Very exact results cannot be obtained in this way, since the various parts of the air-current have not all the same velocity, and the first perception of the smoke or smell corresponds to the arrival of the most rapid portions of it, and thus gives us the highest rather than the mean velocity.

Again we can make use of a very simple anemometer which resembles the hydraulic pendulum (*Cours de Machines,* No. 130), and consists of a light hollow ball, making an angle with the vertical which varies with the velocity of the air. This apparatus is held between the hands of the person who measures the air.

Another method is to walk along a given length of the galleries, carrying one of the common lamps in the hand, and regulating the pace so as to keep the flame perfectly upright.

This method, which appears to be somewhat rude at first sight, is really less so than we might think. When employed always by the same person it gives results which are fairly comparable. It is quite sufficient when it is a question of ascertaining the degree of variation in the velocity from day to day, rather than the total actual volume of the air passing along the gallery.

It can, besides, be applied at any moment, without previous preparation, if we possess a watch with a seconds hand, and if there are several marks along the gallery at stated intervals.

A fourth method is to erect a barrier in the gallery, having an opening of given dimensions in it through which all the air has to pass, then to observe the difference of pressure between the two sides of the barrier, and to calculate the volume of air passing through the orifice as one of the functions of this difference of pressure, by means of a suitable formula. (*Cours de Mécanique,* No. 344.)

Lastly, a final method, which is more laborious, but at the same time more exact, consists in employing a real anemometer by means of which we can measure the velocity directly at various points of the section of the gallery, by observing the number of revolutions which a small wheel, with vanes like those of a windmill, makes in a given time. The mean of these velocities is then taken.

These instruments, which were first proposed by M. Combes, were afterwards taken up and rendered more perfect and practical by various persons, and notably by Messrs. Dickinson and Biram. Biram's anemometer is the one most generally employed at the present day.

Anemometers of this kind must be verified by means of direct experiments, in which they are made to move through masses of air at rest at given velocities. A special formula must, therefore, be used with each instrument in determining the velocity of the current of air at a given point from the number of revolutions of the vanes per minute.

(588) Having disposed of these preliminary matters, it now remains for us to describe, in the first place, how the miner is enabled to direct and subdivide a current of air according to the various circumstances which may present themselves; and, in the second place, to point out the general principles by which he should be guided in effecting the distribution of the air-current throughout the workings of a mine by the means that have been described.

The means of distribution at the disposal of the miner should place him in a position to solve the following questions:

1st QUESTION.—*To compel a current of air to follow a given course in the midst of any network of galleries.* The general means consist in placing stoppings at the entrance of each of the lateral galleries which cross those forming the given circuit. These stoppings sometimes consist of thin partitions of bricks, placed on their edges, with mortar joints, sometimes of more or less thick walls of ordinary masonry, or even of dry walls. At points where there might be a danger of these walls being destroyed by an explosion of fire-damp, they should be made tolerably thick. An ordinary wall of stowing two or three yards thick will resist an explosion better than a thin wall of the best masonry, and that because of the *instantaneous shock* of the explosion. A true *shock* is produced which generates an effort whose intensity cannot be calculated, but which is all the greater and more instantaneous in proportion as the obstacle before it is more unyielding.

If this obstacle is quite *rigid* it will almost certainly be broken.

but the inertia of a large and less incompressible mass cannot be overcome in a short interval of time, and this mass does not move much, nor does it acquire an appreciable momentum. If it is necessary that the barrier in the side gallery should be opened at pleasure, a trap-door is put in place of a stopping. A single door can be made use of if it can be opened temporarily without much inconvenience to the ventilation; but double, or even triple, doors must be employed in the contrary case. The interval between any two consecutive doors should be long enough to hold the longest trains of waggons which traverse the galleries.

The doors should always open in the direction in which the full waggons are travelling. They should shut of their own accord, and this is effected by placing the hinges in an inclined position in the sense required. The edges of the door which fall against the frame, and the edges of the frame against which the door strikes, ought to be lined with strips of cloth if they are required to be very air-tight. The space between the frame and the sides of the gallery should also be filled up so as to prevent loss of air.

The principal doors should be under the control of a trapper, who opens and shuts them as required.

Those doors, on the other hand, which are opened only occasionally, like the doors leading to the furnace, are kept under lock and key, and the key is kept by the person whose business it is to look after the stokers.

Lastly, it is sometimes the case that *hanging doors* or *safety doors* are placed at very important points of the workings. They are attached to hinges placed horizontally, and are supported in a suitable excavation in the roof, where they present no impediment to the passage of the air. If an explosion occurs which carries away the ordinary doors, it leaves the safety-doors uninjured, because, as we have said, violent but instantaneous currents of air like those produced in an explosion are very destructive in the line of their movement; but they produce no sensible effect sideways. The safety-doors can therefore be shut as soon as they are reached after an explosion, in order to restore the air-current to its proper course. They may even be made so that they are shut by the explosion itself, if the support which holds them up is

placed in such a position that the blast of the explosion drives it out.

By means of these doors it becomes possible to restore the main features of the distribution of the air soon after an explosion. It has also been claimed for them that they might be used for isolating spaces in the workings into which the men could retreat, and escape the deleterious effects of after-damp or thick clouds of dust after the occurrence of an explosion.

2nd QUESTION.—*To force air into an advanced gallery which is not in the direct course of the air-current.* This question corresponds to a case of very common occurrence in practice. It includes the ventilation of a sinking shaft, that of a cross-measure drift, and, lastly, that of all the galleries which are pushed forward for purposes of exploration.

The general solution consists in the establishment of two distinct air-ways in the *cul-de-sac* which constitutes the working-place, one serving the purpose of conducting the air-current, or part of it, to the face, the other serving to bring it back to the main air-way again.

For this purpose an air compartment is formed, either by means of boards placed horizontally, or vertically, or a thin brick brattice is built, or a brick arch, or, if the place is large enough, a mass of stowing is built along the middle, or, lastly, if there is plenty of air, and no necessity for husbanding it, loose cloths may be hung up from the roof to the floor along the line of the gallery.

Again, if the gallery is narrow, air-boxes made of wood, or pipes made of sheet-iron or zinc, may be substituted for a brattice. These are joined end to end, and either lie on the floor, or are suspended in the angle of the timbering by means of two small pieces of board.

Lastly, one of the methods very often resorted to, and more especially so in exploring galleries in coal-seams, is to drive two parallel drifts, having a barrier of several yards thick between them, and to make a cross-cut through the pillar every now and then as it is required. The last cross-cut serves to introduce the air from one drift into the other, and the previous cross-cut is stopped up, or stowed up, as soon as the new one is completed.

All these methods, which are shown in figures 469 to 472, and of which a description will be found in the explanation of the plates, are commonly used in mines. We can always employ them in such a way as to bring a current of air as close to a given point as we may desire, and one method, or the other, can be adopted according to the degree of difficulty, or danger, which a particular place may present.

If a ventilating compartment is so small, compared with its length, that the quantity of air passing through it spontaneously is insufficient, the draught may be increased by means of a small fan driven by hand, of the same construction as those employed for producing a blast for cupolas.

In order to produce a current of air in galleries divided in the manner described, the point at which the air enters them requires to be separated from the point at which the air leaves them again on its return back from the face. This is effected by either completely, or partially, closing the passage which the air would naturally take, and so forcing it to take the way that has been prepared for it.

This may be done in some cases by means of a single or double trap-door, or by a fixed brattice, or by a simple cloth stretched across the gallery.

3rd QUESTION.—*To cause two or more currents of air to circulate in the same gallery, and travel either in the same direction, or in opposite directions, without allowing them to mix with each other.* The solution of this question, of which the preceding one was only a particular case, is obtained by simply dividing the gallery into as many compartments as there are separate air-currents.

4th QUESTION.—*To cause one current of air to cross another one without mixing with it.* The general method consists in taking down the roof of one of the galleries for a certain distance on each side of the point of crossing, and at that point itself, and then to make an artificial roof by means of an arch of masonry, or a timber platform at the height of the original roof, and lastly, to cause the air-current to cross over in the empty space existing above the arch or the planks.

The isolation of the current is completed by setting up two stoppings, or two single or double doors, under the part in which the roof has been taken down, according as it is necessary to stop, or to continue travelling through that gallery. Figures 473 A and 473 B represent these arrangements.

5th QUESTION.—*To preserve a passage for air amongst old workings.* It may often be necessary to preserve a passage for air through the old workings, for the sake of shortening the distance which the air has to travel, for instance.

If the method of working is one by which *falls of roof* are provoked, the gallery so preserved will require to be maintained by means of strong timbering, and it should be low and trapezoidal or rectangular in section.

It should be surrounded on the sides and top with a certain thickness of stowing taken from the adjoining waste; and when the heavy falls of roof take place ultimately, this stowing will resist the impact of even large masses of roof, and the gallery will be able to be kept open even for a considerable time.

If the method of working is with stowing, the air-way will be simply a gallery left in the midst of this stowing. If the air-way which has to be preserved through the stowing is of little importance, it can be made by means of wooden boxes, or iron pipes, around which stowing is carefully packed, and this will prevent the pressure from causing them to collapse when the body of the stowing is subjected to the weight of the roof.

6th QUESTION.—*To compel a current of air to divide itself between two galleries in a given proportion.* When an air-current arrives at a point where two galleries branch off and constitute separate passages until the upcast shaft is reached, it rarely happens that these two air-ways are identical in every respect; they may differ either as regards their length or their section, or the temperature which they impart to the air passing through them, &c.

The result is, that one of the air-ways offers less resistance to the air than the other. The air takes the easier way, and is thus more or less withdrawn from the more difficult passage, which may be the very one requiring the larger supply.

When the difference of resistance is very considerable, so is the

difference in the proportion of air which traverses each of the galleries.

For example, if a direct passage were opened between the downcast and upcast shafts, the whole of the air would travel through it, and the distant working-places would be ventilated by diffusion only.

The same result might follow if a door were not sufficiently air-tight, because the resistance offered by the door to the passage of the air might not be so great as that encountered in a long air-way.

It is evident, therefore, that we ought to be in a position to divide the air at a point where two air-ways branch off, *according to their individual requirements.* This is done by leaving the more difficult passage entirely open, and placing a door having a *sluice* or regulator in it in the other one, and varying the regulator as we desire.

It often happens that an ordinary door is sufficient, either on account of leakages, or on account of the quantity of air which passes through it, when it happens to be opened for the requirements of traffic.

(589) The six questions which we have just disposed of completely resolve the practical part of the problem for distributing a current of air. It is easy to see, indeed, after a little reflection, that, if we trace any arbitrary course whatever, simple or complex, upon the plan of a mine between the downcast and upcast shafts, we are in a position to compel the air to travel in the ways we have marked out, by having resort to the practical means which have been pointed out.

The problem is, therefore, solved theoretically also in regard to its more general characteristics. But it is quite clear that the course we must decide upon is not an arbitrary one, but must, on the contrary, satisfy numerous conditions, some of which are merely desirable, whilst others are more or less necessary.

It remains for us to point out in what these desirable and necessary conditions consist. After having described the practical way of dealing with the matter, we have now to deal with the *principles* which this distribution of the air must satisfy.

These principles may be summed up in the following manner

(590). The first principle should be to seek to facilitate the circulation of the air, by making the galleries of as great a section as possible consistently with the magnitude of the deposit, and the method of working it.

It is easy to prove the great importance of this principle. If we consider (conformably to what has been said in the *Cours de Machines*, No. 350) a gas moving in a conduit, and suppose the temperature to be constant, and that we can neglect the small variations of density due to differences of pressure (treating it in fact like an incompressible fluid), we know that the dynamic head lost in friction in the length of the passage is given by the expression,

$$\beta \frac{\chi}{\omega} LV^2. \qquad (1)$$

In this formula β represents a numerical coefficient which depends on the state of the walls of the passage, and increases with the roughness of the walls; χ represents the perimeter, ω the section, and L the length of the passage; and V represents the mean velocity of the air.

On the other hand, if Q is taken to represent the quantity of air, we have $Q = \omega V$; and, consequently,

$$h = \beta \frac{\chi}{\omega} L \frac{Q^2}{\omega^2} = B\chi L \frac{Q^2}{\omega^3}. \qquad (2)$$

If we suppose two similar galleries of unequal section, and if we designate a given dimension of this passage by d, the expression assumes the form

$$h = ML\frac{Q^2}{d^5}. \qquad (3)$$

M is here a numerical coefficient.

The work required to move the volume Q with the dynamic head h can be taken as equal to Qh (No. 583); we have thus:

$$Tm = Qh = ML\frac{Q^3}{d^5}. \qquad (4)$$

We see that for a given value of Q the manometrical depression and the corresponding work diminish rapidly in proportion as d increases.

Thus, when we double the section of the air-way, which is equi-

valent to replacing d by $d\sqrt{2}$, these quantities are reduced in the ratio of 1 to $(\sqrt{2})^5 = 4\sqrt{2}$, or in the ratio of 1 to 5·6. Thus, assuming that, in the first case, a depression of the water-gauge was required amounting to 5 or 6 inches (14 or 15 centimetres), which cannot be produced save by a Lemielle or Fabry ventilator, it will be quite possible to work with a common ventilator, or even with a furnace, when the section is doubled.

If we wished to have the same manometrical depression with a small air-way as in one of large section, it would be necessary to put:

$$\frac{Q^2}{d^5} = \text{constant.}$$

We see that the quantity Q increases as $d^{\frac{5}{2}} = d^2\sqrt{d}$ (that is to say, *more rapidly than the section*); so that the velocity of the current itself increases in the ratio of 1 to $\sqrt{d}$. Thus, for example, a section twice as great, which means $d^2 = 2$, will give, under the same depression, a volume greater in the ratio of 1 to $d^2\sqrt{d}$, or of 1 to 2·4, and flowing with a velocity which is greater in the ratio of 1 to $\sqrt{d}$, or 1 to 1·2. Such will be the result if the manometrical depression is a constant value determined by natural causes, such as the difference in height or temperature of two columns of air.

If we have an artificial ventilation, and desire to adhere *to a constant expenditure of work*, it is necessary to put:

$$\frac{Q^3}{d^5} = \frac{Q^3}{d^6} \times d = \text{constant.}$$

In this case the volume Q increases again if we pass from the gallery of smaller section to one of larger section; but it increases less rapidly than the section, for it is proportional to $\frac{d^2}{\sqrt[3]{d}}$. A section twice as great will give a volume which will be greater in the ratio of about 1 to 1·80, and a velocity which will be less in the ratio of about 1 to 0·90.

Such are the very important results which we obtain by doubling the section of a gallery. It is evident what kind of result we should get if we pass from an ordinary mine gallery having a section of 35 or 40 square feet (3·5 square metres) to galleries of very

large sections like those formed in the workings of certain thick coal seams, or in certain underground quarries, which are comparable sometimes to the large tunnels of canals or railways.

Ventilation is then produced *very easily indeed*, and even with *very low manometrical depressions* it may be made most active. The slightest natural cause is sufficient to determine the depressions required, and this is the reason that natural ventilation is often sufficient in those mines whose workings are of *large section*, and communicate with the surface through *many openings*.

It is not always possible, or indeed advisable, to make the galleries so very large, but the point to be borne in mind is, that they ought to be made as large as is compatible with the other points of view of the question, such as their first cost, and the cost of maintenance in a state of repair, and the latter item increases rapidly as firmness of the ground diminishes. It is necessary again to have the section as uniform as possible, and to avoid every circumstance which can produce eddies, as these add to the friction. Lastly, the galleries which are used only as return air-ways must be carefully watched and kept in good repair, and must not be allowed to become smaller.

There is indeed no good reason which justifies the small dimensions which return air-ways usually have or which they gradually assume when not properly repaired. It might be asserted, on the other hand, that they ought rather to have a *larger section*, *an excess of section*, to compensate for the increase of volume, which the air acquires by becoming heated and charged with gas during its passage through the workings.

(591) Having made the galleries of the size thought most suitable under all the circumstances of the case, we may still increase the section of the air-current by a device which is often resorted to. It consists in causing the air to circulate in two or three parallel galleries instead of in one. If, for example, we desired to ventilate a system of level-course working-places connected together by inclined headings, we should employ the two lower galleries as intake air-ways, and the two upper ones as return air-ways, instead of confining ourselves to the use of the two extreme

galleries, and allowing the intermediate ones to be ventilated by simple diffusion.

This arrangement has an evident advantage, although it is less than it would be if we could double the size of the gallery instead of having two of the same section.

The difference between the two cases results from this, that in formula (2) of the preceding paragraph $\left(h=\beta\frac{\chi}{\omega}L\frac{Q^2}{\omega^2}\right)$, the quantity $\frac{\chi}{\omega}$ is a constant, because with two galleries the perimeter χ becomes double at the same time as the section. Formula (2) takes the form

$$h = M\frac{LQ^2}{\omega^2}, \qquad (2')$$

and, consequently, formula (4) becomes

$$Tm = hQ = M\frac{LQ^3}{\omega^2}. \qquad (4')$$

In this case *a constant depression* gives the air the same velocity, and, consequently, it doubles the volume when the section is doubled if this is done by having two parallel galleries. *A constant motive power* increases the volume less rapidly than the section increases, and, consequently, the velocity is reduced.

It is easily seen that, with two galleries of equal section, the volume increases in the ratio of 1 to $\sqrt[3]{2}$, or of 1 to 1·26, and the velocity decreases in the ratio of 1 to $\frac{\sqrt[3]{2}}{2}$, or of 1 to 0·63.

It should be understood that these numerical results, like those of the preceding number, are *the theoretical limits* to which we approach more and more closely, in proportion as the part of the air-current we are considering increases in importance relatively to the entire current, including the portions in the downcast and upcast shafts.

(592) Another principle, quite as important as the foregoing one, is that of subdividing the air-current into several distinct currents (*splitting* the air).

This principle evidently has many secondary advantages.

It permits us, for instance, to isolate any particularly dangerous

district containing gas from the rest of the workings, and to conduct the current which ventilates it directly to the upcast shaft.

It enables us to avoid sending an air-current through the last of a long series of working-places after it is already surcharged with gas. But the point we must discuss here is the advantage furnished by this system of effecting a general improvement in the conditions of the ventilation.

For this purpose, let us again make use of the formulæ of No. 590.

$$h = \beta \frac{\chi}{\omega} LV^2 = \beta \frac{\chi}{\omega} L \frac{Q^2}{\omega^2},$$

$$Tm = hQ = \beta \frac{\chi}{\omega} LV^2 Q = \beta \frac{\chi}{\omega} L \frac{Q^3}{\omega^2}.$$

Let us suppose, in the first place, a single air-current which traverses all the districts (*panels*) of a mine *in succession*, and, in the second place, that this single current is subdivided into m equal currents which traverse the same number of districts, which we shall also suppose to be equal.

We shall evidently obtain the new value of the depression h if we retain the same values for $\frac{\chi}{\omega}$ and ω, and replace L by $\frac{L}{m}$, and Q^2 by $\frac{Q^2}{m^2}$.

We shall thus have for the new expression:

$$h' = \frac{1}{m^3} \beta \frac{\chi}{\omega} \frac{LQ^2}{\omega^2} = \frac{1}{m^3} h.$$

In the same way, remarking that Q then retains its value, the value of Tm will become

$$T'm = h'Q = \frac{1}{m^3} \beta \frac{\chi}{\omega} L \frac{Q^3}{\omega^2}.$$

Thus a simple subdivision into two currents, a subdivision which takes place of its own accord in certain cases, for example, when a cross-measure drift intersects a seam in which workings are driven both to the right and left hand, is sufficient to reduce to one-eighth of their former value the depression and the motive power required in order to keep *the same quantity of air* in circulation.

If we work two seams at the same time, and distribute the

current between them both, and have two currents in each, which is equivalent to making $m=4$, then it is to the one-sixty-fourth, and not to the one-eighth, that we can reduce the depression and the motive power.

This is equivalent to saying that the depression becomes *inappreciable* if it is not more than a small fraction of an inch to begin with, or, in another way of putting it, if the depression is still appreciable after the subdivision has been made, then the ventilation would have been practically impossible on account of the great depression required, if we had attempted to ventilate the mine without dividing the air-current.

It should be remarked, that when we have succeeded in subdividing a given mass of air in this way until the manometrical depressions are very slight, the influence of the causes which produce natural ventilation can no longer be left out of account. If these causes are equivalent to a certain depression, that depression will either lessen or add to the depression calculated above, according as the causes which produce it act in the same sense as the current is travelling, or in the opposite sense.

Suppose the former case, and take it for granted that the causes we are discussing are sufficient to produce the n^{th} part of the necessary depression when the current is divided.

The amount of depression which will have to be produced artificially will be measured by the expression

$$h_1 = h'\left(1 - \frac{1}{n}\right).$$

Before the current was divided, the *total* necessary depression, according to what we have seen above, was $h = m^3h'$, and the depression required to be produced by artificial means was

$$m^3h' - \frac{1}{n}h' = h'\left(m^3 - \frac{1}{n}\right).$$

The ratio of these two artificial depressions is thus that of the quantities $1 - \frac{1}{n}$ and $m^3 - \frac{1}{n}$, or $\frac{n-1}{m^3n-1}$.

If we suppose, as we we did just now, that $m=4$, and if we

assume, as we can reasonably do when discussing very small depressions, that $\frac{1}{n} = \frac{1}{2}$, the quantity $\frac{n-1}{m^3 n - 1}$ becomes equal to $\frac{1}{127}$.

Thus it is no longer $\frac{1}{64}$, but only $\frac{1}{127}$ of the depression that has to be produced artificially.

This rapid decrease is a perfect explanation of the fact already pointed out, that even an extensive mine which communicates with the surface by a certain number of distinct orifices is sometimes sufficiently well ventilated without our requiring to have recourse to artificial means, and often without our having to take much trouble in the interior of the workings, save to place a door here and there so as to prevent too direct communication between one orifice and the next adjoining one. This multiplicity of orifices, placed naturally under such conditions that the air has a tendency to enter by some and go out by others, favours the spontaneous division of the workings into a certain number of districts, which are ventilated by distinct currents, and the whole mine is sufficiently well ventilated without our having to produce a special manometrical depression at any point.

(593) The effects of subdividing the air-current, as we have pointed them out above, have been calculated on the supposition that the total quantity of air was constant. But it is not always necessary to be bound by this condition; for it may happen that, when the subdivision is pushed too far, each partial current may be practically insufficient, and that the air becomes, so to say, stagnant in front of the faces; it is better, on the contrary, to have *an appreciable current of air everywhere*, both for keeping the atmosphere of the mine healthy, and for facilitating the process of diluting, and carrying away gas at the points where it is disengaged.

As we did before, when speaking of the section of the air-current, we can lay down the condition of retaining either *the same depression*, or the *same motive power*, after the subdivision of the current, as before.

In the first case, adopting the notation of the preceding paragraph, we must make $h' = h$, and this requires the quantity $\frac{Q^2}{m^3}$ to remain constant.

The quantity $\frac{Q}{m}$, that is to say, the air travelling in each separate current increases therefore proportionally to $\sqrt{m}$, and the total quantity Q to $m^{\frac{3}{2}}$. Thus if a single current gave, in the first instance, a certain volume of air, a division into four currents will give a quantity eight times as great, and consequently each partial current will have a volume twice as great as the original one. Thus we have the remarkable fact that each of these currents is *more active* than the total current would be.

If we wished to retain *the same motive power* in operation instead of the same depression, it is the quantity Tm, and, consequently, the quantity $\frac{Q^3}{m^3}$, which should remain constant; that is to say, each subdivision of the current would convey the same volume of air as we should obtain with the single current.

These last results are easily set forth and remembered, and they are very well adapted to fix the mind upon the advantages to be derived from a subdivision of the air-current. They are, on the other hand, *theoretical* results which stand good in practice with the restrictions pointed out at the end of No. 591.

(594) The third principle is to direct the current of air in the best way to assist the dispersion of foreign gases. This is effected by causing it to flow in the same direction that the gas would take at the instant of its escape from the strata.

As fire-damp is the principal gas that has to be considered, because of the deplorable disasters which its accumulation sometimes produces, and as this gas is lighter than air and tends to rise, the application of the principle to fiery mines signifies the adoption of *an ascensional current.* This means that the current should traverse the working-places it has to ventilate *from the lowest towards the highest,* and never in the opposite direction. The air ought to arrive at the lowest part of the field of operations, and ascend through the working places, and the return air-way should be made at the highest part of the field. When the successive floors of any given working area are taken in descending order, each cross-measure drift serves *at first* to convey the air to the

workings situated above it, and *afterwards* it is employed as a return air-way for the workings when they have progressed below its level.

Such ought to be the rule, and in Belgium so much importance is attached to it that it is considered to be strictly obligatory upon colliery owners. It has, indeed, a real importance, and when, at the same time that it is applied, care is taken to stow the rubbish so close to the faces that the current of air passing along them has a sensible velocity, it is possible by means of the eddies to clean the gas out of small cavities at the re-entering angles of the overhand stopes employed in Belgium, in which it is liable to accumulate.

There is no imperative law of this kind in France * like that of Belgium. The regulations of the latter country permit this law to be departed from in certain particular cases, but only after a careful examination of the question has been made.

We think that such exemptions may, in certain cases, be perfectly rational.

If it is a good thing to have ascensional ventilation along the faces where the gas is given off, we know that when once the gas and air have been thoroughly mixed they never separate again. It thus appears that when an air-current has traversed the working-places, and become charged with gas, we may look upon it as a homogeneous mixture, and cause it to return through a descending gallery in which no gas is given off, if such a course should be thought advisable in the interests of the general ventilation of the mine.

As an extension of the rule for an *ascensional current*, we should prevent as much as possible any excavations in the form of *culs-de-sac* being made and kept open in places where explosive mixtures might be given off or lodge, which the air-current could not sweep away.

It is for this reason that, when an opening has to be made between two levels in a fiery part of a colliery, it should be driven from the higher towards the lower level, rather than in the opposite direction. If any circumstance, such as the presence of water,

* Nor in the United Kingdom.—*Translators.*

makes this arrangement inconvenient, the place should, at any rate, have its return air-way very close behind the face. This is the reason also that stalls going towards the rise are more difficult to drive in a fiery seam than those on the level course or dip. And for the same reason, if it is necessary to block up an inclined drift in connecting two air-ways at different levels in order to force the air to the forebreasts, it is advisable to place the stopping at the very bottom of it rather than at any other point.

(595) The fourth principle is to arrange matters so as to have two entirely distinct passages for the entrance and return of the air, or, more generally, to take care that the isolation between the intake and return air-ways is complete at every point of the circuit.

In No. 249 we have already insisted upon the importance of having the downcast and upcast entirely distinct. This appears to us to be an *absolute necessity* in fiery mines. We referred, then, to the example of England, where the conditions of isolation are established by law. We can also quote the law which bears on this point in the state of Pennsylvania, where, as is well known, the production of coal has reached an enormous development. A law which was recently passed in that State ordains that every mine in which more than twenty men are employed at the same time must be provided with at least two orifices separated from each other by an interval of not less than 150 feet of solid rock.

These two examples entirely confirm us in our opinion that a coal mine of any importance cannot be considered to be in a satisfactory condition so long as the intake and return air-currents traverse the same passage, whether pit or gallery, in which they are separated from each other by a mere brattice.

A division of this kind it is true is the only means of ventilating so long as there is but a single opening to the surface. It must, therefore, be allowed as a provisional measure; but even when a brattice is established provisionally it ought to be made secure, and kept in good repair, so as to avoid the leakages of air, which may be very considerable in consequence of the numerous joints, and

especially in places where it is necessary to have a somewhat large manometrical depression.

This arrangement ought, we repeat, to be only provisional, and it should be superseded as soon as a communication can be made with another pit, or drift, which also communicates with the surface.

When once this communication has been effected, the means of ventilation which are to be definitely employed ought to be put into operation, and it is only from the day that this is done that the situation can be considered satisfactory.

While waiting for this to be completed we have recourse to temporary expedients, which are generally sufficient, since the workings requiring to be ventilated are very restricted in extent.

Thus, for example, in the case of a sinking pit, the theory of ventilation set forth in Nos. 562 *et seq.* shows *à priori*, and experience confirms it, that if the pit has a large section it may be ventilated, even without a brattice, in winter, whilst the mere existence of a brattice in it may be insufficient in summer, and it may be necessary to resort to artificial means to produce and maintain a current of air. It will be necessary, for instance, in summer at least, to prolong the brattice or the air-pipe above the top of the pit in order to have a certain difference of level between the points of entrance and exit of the air. We might also provide each of these orifices with a *wind-sail*, one facing the wind, the other open in the opposite direction, in the same way as the holds of ships are ventilated. We might, lastly, prolong the air-pipe, and make it terminate in a chimney, or under the bars of the boiler furnace or of a special furnace, and so on.

(596) What we have said regarding the isolation of the intake and return air-currents may be said also, although in a less imperative and less general manner, of two currents circulating in the same gallery in any part of the workings, and separated from each other by a simple brattice.

A brattice of this kind may be destroyed by an explosion in any gallery, as well as in a shaft, and the ventilation of a part if not of the whole of the workings may thus be brought to

a standstill. Brattices ought, therefore, to be avoided as a definite means of distributing the air, at every point where their accidental destruction would stop the ventilation in a district of some extent.

It is never practically impossible to suppress the use of brattice, for, as we have seen before, a single gallery can always be replaced by two galleries connected together by means of cross-cuts (*thirlings*). The cross-cuts are stopped up successively in proportion as the face advances, care being taken to employ a mass of rubbish of some thickness in each of them, and then we know that if an explosion takes place it cannot destroy the isolation of these two galleries, whatever may be its intensity.

(597) The preceding paragraphs contain all that can be said, in a general way, respecting the ventilation of mines. Leaving out special details, which particular cases might require to be adopted, the general arrangements of ventilation can be described in the following manner:

A district is usually worked out in a series of floors taken in descending order. (Nos. 259 *et seq.*) There is a downcast and an upcast shaft.

Cross-measure drifts which intersect the seams are driven in succession from the lowest point of each floor.

Usually when one floor is in process of being worked out at certain points, other parts of it are prepared by prolonging the cross-measure drift in both directions, until it intersects the other seams, and, at the same time, the preparation of the next lower floor is begun.

Matters being supposed to be in this state, the body of air descends the downcast shaft, and divides itself, for the most part, between the two cross-measure drifts which meet at the hanging-on-place of the floor in course of being worked out. The remainder descends to the bottom of the shaft, for the purpose of ventilating the new cross-measure drift, by means of a brattice or air-pipe, and it then returns to the upcast shaft, if that shaft is already sunk to the same level. If the upcast has not been sunk so far, the air returns behind a provisional brattice in the winding-shaft below the hanging-on-place, and as this return air is still

comparatively pure it may be allowed to mix with the current entering one or other of the cross-measure drifts. Each of these latter currents gives off a portion of its volume as it passes through each seam, and this again divides itself to the right and left, and ventilates the working-places on each side of the cross-measure drift, travelling upwards along the faces and into the return air-way to the rise of the shaft; it finally enters a higher cross-measure drift, which acts as the general return air-way, and has, with this end in view, been put into communication with the upcast shaft.

The ventilation of the drifts cross-measure beyond the last seam that has been won, is effected by means of a brattice, which diverts the current that has been conducted as far as the entrance to the *cul-de-sac.*

Such is the general, and to some extent standard, arrangement of the ventilation of a mine. We have only to add a last detail affecting the case of slightly inclined seams, in which a floor or storey of a given height corresponds to a great distance along the line of dip. It is this: that it may be a matter of convenience in regard to the ventilation, as well as for the purpose of applying certain methods of working, to divide the field on the rise side into a series of separate panels, which are worked and ventilated independently of each other, and thus give rise to a new subdivision of the two partial currents which have entered the seam from the cross-measure drift.

(598) We shall add, finally, that when the ventilation has been well organized, the duties of the engineer are by no means at an end, since it is *quite indispensable* that he should *personally* supervise the system that has been established.

During his rounds he ought frequently to visit the return air-ways, which, as we have said above, are too often neglected; he should be consulted regarding all the changes of importance that are contemplated in the conduct of the ventilation; he should give instructions to have the air-currents measured at different points of the workings by one of the simple means mentioned above; he should pay attention to great variations of the barometer; he should be in a position to assure himself, by inspecting a mano-

meter within his easy reach, that the ventilating-machine is working with the normal depression, and, if this is not the case, he should quickly ascertain the cause of the disturbance; he should see that every morning, and especially after the stoppage of work on Sunday, the whole of the working-places, and the entire circuit of air-ways, are visited before the descent of the shift, and that all the suspected or dangerous places are distinguished by a special mark or fence, prohibiting them from being entered by the workmen; he should, as a matter of principle, prohibit the use of naked lights in fiery mines, except at certain specially appointed places, and he should also prohibit the operation of blasting in all working-places in which the gas shows a blue cap on the flame of a lamp.

Lastly, he should take care that, in case of an accidental stoppage of the ventilation, the workmen are immediately recalled to the bottom of the down-cast shaft, and conveyed to the surface as soon as possible.

We could extend and increase the number of these suggestions; but we must limit ourselves to what has been already said, and we will only add, in a general way, that it is not possible to take too many precautions and measures of prevention in a matter of this kind, and that the question of ventilation in a fiery mine is one of the utmost importance, and ought seriously to engage the attention of the whole professional staff; for, if once a fault be committed, or even a slight neglect, it may give rise to the direst consequences and entail the most grave responsibilities.

§ 4. On the Lighting of Mines.

(599) The means of giving light to the workmen who labour in the interior of mines is connected in a natural way with the service of ventilation. It might be thought that it merely occasions a certain daily expenditure for each workman employed, and that, after naming this sum, we might dismiss the subject without having anything else to say about it that could be of use.

It may be replied that, although this expense is not often shown in the cost of the mineral, perhaps not so often as it ought to be,

as it is to some extent scarcely apparent, being charged to the workmen and comprised in his daily wages, it is nevertheless a real charge of some importance to the mine. It is seldom under 1¼d. to 1¾d. per man per day, and it often rises to 2d. and 2½d. or more; that is to say, we shall not be exaggerating if we take it at 5% or more of the gross earnings. It is somewhat important, therefore, to control it, and to avoid the abuses and waste which easily creep into this department.

The best guarantee we can have in this respect is to arrange, as far as local usage will permit, that each workman provides himself both with a lamp and with oil. If the lamp is provided by the owner of the mine, it ought to be numbered so that it can be traced, and the workman who uses it should be responsible for its loss or for any damage it may sustain.

Waste of oil is inevitable if it is supplied by the mine; many workmen will ask for more than they actually require, and put aside some for their own private use. It is better, therefore, if they have to buy it for themselves. (We are speaking only of ordinary lamps with a naked flame at present).

Miners' lamps are constructed differently in different localities. The most primitive type, which is similar to the antique lamp, consists of a flat vessel, partially covered, which holds the oil. (Fig. 474.) The wick lies amongst the oil, and one end only comes out at the spout. A handle at the side opposite to the spout serves to carry it. Sometimes instead of oil a solid grease or tallow is employed, which melts near the flame. Lamps of this kind give a fitful and smoky flame; the wick must be pricked up very often, and the oil is spilt when the lamp is accidentally upset or too much inclined. It has been made more perfect by adopting the *turnip*-shape shown in fig. 475, and lamps of this form are employed in many localities, and more especially in the mines of the Loire. These lamps, which are of a rounded flattish shape, are entirely closed, excepting an opening left for the wick, and the size of that opening can be regulated at pleasure There is also a small hole for admitting air, and thereby allowing free play to the capillarity of the wick. These lamps are generally constructed of sheet iron, and are, therefore, very strong. They are.

hung by a handle, which serves to carry them, and the handle is provided with a pointed hook, which is driven into the timber at the most convenient height for giving light to the workmen, when they are labouring in their stalls.

Sometimes there is a pin attached to the handle by means of a little chain, for the purpose of picking the wick, and raising it, in proportion as it burns away.

These arrangements are very practical; for the lamp is easily handled and easily carried, and may be knocked about or overturned without spilling the oil or being damaged.

In mines in which the men have to make long ascents or descents by means of ladders, such as those of the Department of the Nord, before the introduction of cages for lowering and raising the men, the same general arrangement may be employed as far as the lamp proper is concerned; but, instead of hanging loosely from a hook, the lamp may be fixed to the middle of a handle with a long point. The wooden handle serves for carrying the lamp in the hand, and the spike has two different uses. It can be employed, like the pointed hook we described above, for fastening the lamp to the timber when necessary. But its principal use is to enable the lamp to be carried in the miner's cap by means of a copper sheath fixed in front. In this manner the workman can have the free use of both hands in climbing; and more than this, the lamp is carried on his head, and shows him the rungs of the ladder which he is about to grasp.

This arrangement, which is represented in figure 476, is, therefore, very convenient for climbing ladders; but, on the other hand, the fixed handle is less convenient than the loose one in travelling along the roadways, as the latter can be held in the angle between the thumb and fore-finger, at the same time leaving these two fingers almost free. We think, therefore, that the lamps employed at Saint Etienne are more convenient for travelling with everywhere, except on ladders.

In certain metalliferous districts, the lamps are provided with reflectors which shade the eyes from the direct rays of the light, and make them more sensible to the reflected rays which are thrown upon any point of the working-place. The shade consists

of a small wooden case, lined with thin sheet brass or tin plate, and the lamp is fixed inside. At the back of the shade there is a long hook, by means of which it can be carried in the hand when the workings are inspected, or hung to a string round the neck when ladders have to be climbed.

If care is taken to reduce the size of the lamp-case or shade as far as possible, this arrangement is very convenient for examining a mineral vein in an *end* or *stope*.

The flame is also protected from draughts, especially if the case is provided with a glass front which slides up and down in a groove; it then becomes a veritable lantern, and can be used outside the mine and exposed to the wind.

Sometimes candles are employed, which are carried either in ordinary candlesticks or in save-alls, or, lastly, in a lump of clay, into which they are stuck, the clay being carried in the hand. This method of lighting is not a good one, as the candles are apt to run very much if they are carried rapidly, or if the wind is strong, or the temperature high.

In some localities this method of lighting is reserved as a distinction for strangers who are visiting the mines.

Possibly one may see a little better with candles than with an ordinary lamp; but as a set-off to this they are much more dirty, and they are very inconvenient for carrying on ladders.*

They should be reserved for those who wish merely *to take a walk underground*, and lamps should be given to those who really mean to *visit* the mine.

(600) The mode of lighting by means of oil in open lamps is almost universally adopted. The nature of the oil is of little or no importance, provided it is purified to about the same degree. Olive oil is employed in the south of France, colza in the north, and sometimes also walnut oil, which is said to have a certain superiority in bad air.

The daily consumption for each workman varies between 4 and 6 ounces (124 and 186 grammes), according to the size of the wick

* Candles are not inconvenient for climbing when fixed upon the hat with a lump of clay, as is done in many of the English metal mines.—*Translators.*

and the duration of the shift. Suppose the price to be 5½d. per pound (1 fr. 20 cents. per kilo.), this would make from 1½d. to 2d. (15 to 20 centimes) for oil alone, leaving out of account the cost of wick, and that of keeping the lamp in repair.

With oil of suitable quality, and the wick in proper order, these lamps will burn in any atmosphere in which men can live. There is such a close connection between these two phenomena, which are also chemically identical, that they both cease when the surrounding atmosphere has become deteriorated to a certain extent.

In general, therefore, we can penetrate into, and live in, an atmosphere in which flame continues to burn with its usual brilliancy, if we except the presence of fire-damp and of some noxious emanations, which act like poisons even in slight proportions.

When the air is much charged with irrespirable gas, and notably with carbonic acid, the flame becomes small and less luminous, and the least movement serves to extinguish it. It is then time to withdraw, and the working-place should not be again entered until it can be properly ventilated; for, although the danger to the men may not be imminent when the flame of a lamp is unsteady and goes out every minute, yet it is liable to become so without any further warning: besides, a long stay, in a medium so nearly approaching an irrespirable condition, is always hurtful to the health, and may, with certain predispositions on the part of those who are exposed to it, give rise to serious results.

It is not always possible to ventilate places containing bad air, at least within the time at one's disposal. If it is urgently necessary to carry on work in a place in which the lamp will no longer burn, the men are frequently relieved, and there are others ready to succour them in case of an emergency. Light is directed upon the spot from a distance as well as possible, by placing large lamps at points where they can still burn, and using reflectors. Sometimes the sun's rays are converged in the same manner.

In place of this kind the electric lamp, invented some years ago by MM. Dumas and Benoist, may be employed with advantage. This lamp consists of three distinct parts, namely, a Bunsen cell and a Ruhmkorff coil, which are kept in the same case. The case resembles a cartridge pouch, which can be carried about. Lastly

there is an Geissler tube, which, as is well known, has the property of changing the electric spark into a kind of luminous sheet, occupying the whole of the interior of the tube. The last part of the apparatus is either fixed to the pouch, or can be carried in the hand if desired.

This lamp, whose various parts are represented in figure 477, is destined to be of good service in certain exceptional cases, where ordinary lamps will not burn, or where it is dangerous to employ them. The luminous brush can only be produced in a vacuum. It ceases to exist if the interior of the tube is put into communication with the atmosphere in consequence of a breakage, and, consequently, it cannot produce an explosion, supposing even that its temperature were sufficiently high, which it does not appear to be. It may also be remarked that the same electrical current which illuminates the Geissler tube may be employed for firing shots, and it is thus more convenient than an apparatus fixed at a distance from the working place in which the shot has to be fired.

(601) So much has been attempted and carried out successfully by physicists of late years, in the way of applying the electric light to purposes of illumination under various circumstances, that the idea of lighting mines by its means was bound to be brought forward and tried.

But the first objection to its introduction is the relatively high cost of producing it, so far as we have seen up to the present day; and the second objection is, that its luminous rays are of such an intensity as to blind the eyes of those who look at it, and that it lights up so strongly any objects exposed directly to its rays, that everything else appears by contrast to be plunged in profound darkness. It is, therefore, very well adapted for producing brilliant fixed lights, such as those of lighthouses, and very unsuitable to illuminate all the points of a given space with a diffused light.

Lastly, we may state the particular objection to its employment in a mine to be this, that, since it cannot be applied except at fixed points (for it would be too expensive, as well as unnecessary, to give each workman a Dumas lamp), it is but badly adapted to the illumination of irregular and scattered excavations in which

miners are accustomed to work, and the form of which varies from one day to the next.

It appears to us, therefore, that the idea of illuminating a mine with the electric light should be relegated to the number of chimerical propositions which it is not worth while even to attempt to solve.

(602) The same may be said of the idea, which has often been proposed, of lighting mines by means of fixed lamps, instead of giving each workman a lamp, which lights his steps wherever he goes, as well as his working place.

If we supposed the electric light to be replaced by mineral oil, or by coal gas manufactured, if we like, in the mine itself, close to the place where the coal is obtained from which the gas is made, the inconveniences of having a fixed light would still be present in almost the same degree as in the former case.

This inconvenience consists in the fact that, when a mine is illuminated by means of fixed lights, its whole extent requires to be illuminated, and that an enormous expense would be thereby incurred, relatively to that which is necessary according to the present system. The rule at present is, that any given point of a mine is left *in darkness*, and is only lighted as required when a man is working there.

We may doubtless employ fixed lights at points which are always occupied, and ought to be well lighted, such as, for instance, the hanging-on-place at the bottom of the shaft.

The working places are also lighted in the same way by the miners' lamps, each setting up his own according to the requirements of his work; and in this way places are better lighted than if a smaller number of stronger lights were fixed in invariable positions for the same purpose.

But *there is no necessity whatever* for illuminating the galleries which stretch from the pit-bottom to the working places, and form the greater proportion of the interior empty space in a mine.

To do otherwise would be to act in the same way as if we had here and there in a large house a room that was occupied, and went to the trouble and expense of lighting up, not only those

rooms themselves, but also all the others, as well as the staircases, landings, and all the outbuildings of the house.

Such a proceeding might be convenient, but it is not by any means necessary, or practically useful, and it would occasion a heavy expenditure, which might perhaps be consistent with the practices of a luxurious mansion, but would be entirely out of the question in the case we are considering.

We think, therefore, that the idea of lighting the whole of the workings of a mine by any kind of fixed lights is not more practicable than that of applying the electric light.

It is necessary, we repeat, that each workman—hewer, timberman, hauler, or other—should be supplied with *his own lamp*, and that he should be able to change its position *at every instant, and at his will*, so as to throw the light on that part of his work which most requires it.

Contrary opinions find expression occasionally; and it is said that, looking at the extension of lighting in towns, and the new means of lighting placed at our disposal by the progress of science, the time will come when the interior of mines will be flooded with light like an arcade in a large city. We believe, however, that the persons who entertain and express these ideas have not formed a correct notion of what is wanted in the case in point.

(603) We think that, after what has been said, lamps more or less analogous to those described at No. 599, placed in the hands of every workman in the mine, are, and will probably continue to be, the common and normal means of lighting.

It is only in a very exceptional case, and one that is confined to coal working, or rather to a section of these workings, that this means should be considered to be insufficient. The case we refer to is that in which the mine to be worked gives off fire-damp; and, consequently, where explosive mixtures may be formed accidentally, and are liable to be ignited by the flame of an ordinary lamp having *a naked light*.

Theoretically, it is true that a mine of this kind ought to be ventilated with an excess of air, so that the body of the gas disengaged during a given time, supposed to be produced at a

uniform rate and diluted with the body of air introduced during the same time, becomes harmless, and even passes away entirely unperceived; but the production of the gas *may not be uniform*, and the dilution *cannot be instantaneous*. It may occur that certain distant places are not sufficiently ventilated; that there are excavations in which gas can accumulate; that a large fall of roof, or an abrupt drop of the barometer, causes the gas to come out suddenly from the cavities in which it is contained, and from the old workings; that the unexpected striking of a large blower brings in a great body of it in an instant, &c. &c.

In these various circumstances any flame whatever, whether it be that of a lamp, or that of the fuse of a blasting-shot, or that of the shot itself, may give rise to an accident. Again, it may happen that a gallery which is clear to all appearance, but ventilated by a slow current, presents a series of small accumulations of gas lodged between the caps of the timbering, which when kindled form a kind of train, like one of gunpowder, when an explosion takes place near any one of them. Gas lighted in this way may give rise to extensive explosions.

A stall in which there is a permanent cap on the flame of the lamp ought to be abandoned until it can be ventilated.

A stall in which this phenomenon, although not permanent, is liable to occur frequently, ought to be the object of particular precautions. The employment of powder should be entirely prohibited in it, or, at any rate, a shot should not be fired in it until a special examination has proved the absence of explosive gas in the vicinity. It is, moreover, important that the shot should be ignited by means of substances that burn without flame.

Lastly, in a working place like the one we have just described, and in all the places near it, or even in the whole workings of a mine in which such circumstances can arise, the class of lamps known under the name of *safety-lamps* should be substituted for those we have described in the preceding pages.

(604) In their primitive form, safety-lamps are known by the name of *Davy lamps*, from the name of the philosopher who invented them.

They depend upon the fact that an explosive mixture cannot be ignited until it is heated to a sufficiently high temperature at one point of its mass by the contact of another body in a state of combustion. If, therefore, a flame, such as that of a lamp, is surrounded by a network with meshes formed of a good conductor of heat, and placed sufficiently close together, and if this apparatus is immersed in an explosive mixture, the gas will ignite when it comes in contact with the flame of the lamp, and the combustion will extend back to the inner side of the envelope; but the gas which is in a state of combustion will be obliged to subdivide itself into numerous small distinct jets before it can traverse the meshes of the network, and each of these jets will be cooled by contact with the wires, and will be extinguished after having traversed the apertures; the combustion cannot, therefore, be propagated to the exterior of the network.

Such is the very simple principle upon which Davy lamps depend—they are safe under the ordinary conditions which occur in practice; but even their very principle shows that their safety cannot be absolute. The network acts as a cooling medium only by becoming itself heated, and it will cease to act if, by prolonged contact with the flame in its interior, it becomes heated to a temperature equal to, or nearly equal to, that of the mixture which burns in its inside.

It ought never to be kept burning in an explosive mixture where the gauze is filled with flame; but it should be lowered towards the floor, and withdrawn gently, and without any rapid movement before the gauze has time to be heated to any considerable extent. A rapid movement would increase the rapidity with which the jets traverse the meshes, and would, consequently diminish their refrigerating action. For the same reason a current of air which can deflect the flame freely, and carry it against a point of the network, like a blow-pipe flame, may at the end of a certain time cause the flame to pass at that point.

Thus it may be said, in a general way, that the Davy lamp is *safe* in this respect, that it will not cause a general explosion at the instant a quantity of explosive gas is formed around it, and comes in contact with its flame; but it would cease to be safe if it were

allowed to remain in this mixture while work was continued. It is, therefore, necessary to take hold of it immediately, pull down the wick, and lower the lamp quietly to the floor of the stall; or, if work is going to be discontinued, the workman ought to withdraw himself, carrying his lamp in such a way as to protect it from the wind, and using his cap or clothes for that purpose if necessary.

When handled carefully in this manner, this lamp offers a fair degree of safety. All the same, it does not, in any way, allow us to dispense with good ventilation, although it prevents accidents which would often happen when a working place, or district of a mine, became filled with explosive gas in spite of the good ventilation.

It is only by experiment that we can decide the conditions under which the network which surrounds the flame must be constructed in order to exercise the proper refrigerating action.

The gauze usually employed is made of iron wire $\frac{1}{40}$ to $\frac{1}{50}$ of an inch in diameter ($\frac{5}{10}$ to $\frac{6}{10}$ of a millimetre), and presenting about 784 apertures to the square inch (121 to the square centimetre). The gauze is made into the form of a cylinder about 2 inches (5 centimetres) in diameter and 8 inches (20 centimetres) high, and having either a double gauze or a close end at the top. This kind of chimney, which is called the *gauze*, is fixed to the lamp, and completely surrounds the flame. It ought to be fastened in such a way that the workmen cannot remove it, or at least cannot do so without difficulty. A large number of locks, into the details of which we do not here intend to enter, have been proposed or applied.

In order to snuff or raise up the wick the workman makes use of a bent wire, which passes through the oil reservoir in a small tube soldered to the top and bottom of the lamp. He can perform this operation without taking off the gauze.

The lamps are given out to the workmen trimmed, lighted, and locked. Each man is expected to examine his lamp to see whether it is properly locked, and whether the gauze is in good condition at the time he receives it, and he then becomes responsible for the contravention of the rules of which he would be guilty were his lamp found at the face either in an unlocked or damaged condition.

The workman gives up his lamp at the end of his shift; the lamp-man inspects it, cleans it, and fills it with oil, and at the commencement of the next shift he restores it to the workman lighted and locked.

The repairs of a lamp of this kind include those required for the lamp itself, which are not of any particular interest, and those required by the gauze. This essential part of the apparatus is liable to be crushed by a falling stone, or to be pierced by a clumsy stroke of the pick, and, in either case, it must be at once renewed; for the least injury renders it useless. The slightest defect of this kind can be detected by holding it before the eye in daylight.

On leaving the mine the gauze is always more or less charged with dust, and smeared with oil, which spreads over it if the lamp happens to be overturned. The lamps are cleaned in two different ways. Sometimes they are heated in a kind of stove until the organic matters are carbonized, and then they are cleaned by means of a coarse brush. This process is an excellent one as far as the cleaning is concerned, but the gauze soon becomes deteriorated by oxidation. Sometimes they are steeped in a hot alkaline solution or in soapy water, which also eliminates the grease, and then they are brushed, rinsed out in clean water, and dried with a gentle heat.

Self-acting machines have been constructed which shorten or greatly facilitate these operations. Small machines of this kind will be found very useful at large mines, where the lamps are counted by many hundreds, all of which have to be carefully cleaned, inspected, and trimmed in the interval between two shifts.

(605) Figure 478 represents a lamp such as we have just described, and of the kind most commonly employed in most parts of England, France, and Germany.

It is still almost identically the same as when it came from the hands of its inventor.

Notwithstanding the undoubted services which it has rendered, it is by no means beyond the reach of criticism in this form.

In the first place, as we have said, it does not offer absolute safety, and we have described the conditions under which it may be considered to be comparatively safe.

Besides, the objection is made against it that it does not give enough light, especially towards the roof, and this is no doubt a very important matter as regards the danger of falls.

The defect of lighting the roof insufficiently is due either to the double gauze or to the solid top with which it is usually provided, so as to enable it to be carried by means of a ring or hook without the chance of one's hand being burned by contact with the hot gases.

The defect in lighting horizontally is due to the presence of the gauze, which intercepts a considerable part of the luminous rays emitted by the flame. With a wire $\frac{1}{50}$ of an inch in diameter, and with 784 apertures to the square inch, it is easily seen that, in the width of an inch, the space is filled with wire to the extent of $28 \times \frac{1}{50} =$ ·56, and that there is consequently only ·44 of empty space left, and that therefore, if we take into account the crossings of the wires, the space filled up is represented by the fraction,

$$0{\cdot}55 + 0{\cdot}55 \times 0{\cdot}45 = 0{\cdot}55 \times 1{\cdot}45 = 0{\cdot}7975\,;$$

that is to say, in round numbers, the wire represents $\frac{4}{5}$ of the space and the apertures $\frac{1}{5}$.

We do not suppose that $\frac{4}{5}$ of the light is lost, since part of it is reflected through apertures at the opposite side to that towards which it is first directed, but it is obvious that a large proportion of it is absorbed.

The Davy lamps give, therefore, a very poor light, and this constitutes a serious inconvenience in practice.

This inconvenience is bad enough on its own account, because of the dangers arising from falls in the working places, but it may be still more serious from another point of view, when it is pleaded by the workmen as a more or less reasonable excuse for opening their lamps at the faces, notwithstanding the most stringent regulations framed to prevent such an occurrence.

This repugnance of the workmen to adopt a system which protects them from an eventual danger, but puts them to permanent inconvenience, is more or less marked according to the customs that have prevailed amongst the working population of the district. In the North of England, for example, that is to say, in the districts

where the Davy lamp was first introduced, we see the simultaneous employment of safety-lamps in one part of a mine, and of naked lights in another. On the Continent, on the other hand, when a mine gives off gas at certain points, safety-lamps are used everywhere save perhaps *at the hanging-on-place at the bottom of the downcast shaft.*

The employment of naked lights at the last point is not itself absolutely safe, as we have lately seen from the example of a very serious accident, which arose from the ignition of gas at the naked lights at a pit-bottom.

(606) After what we have just said, it will be obvious that the attempts to modify the Davy lamp for the purpose of increasing its safety, or augmenting its lighting power, have not been made without some real incentive to do so. Numerous trials have been made by different people, and notably by Messrs. Upton and Roberts, Clanney, Dumesnil, Mueseler, Combes, Boty, Eloin, Morison, &c. These attempts, which have been more or less successful, have had all the following points, or some of them, in view; but we would refer the reader, who wishes to become acquainted with the details, to the special accounts published by the inventors themselves, or under their direction.

1st. To make the lamp give a better light by replacing part of the wire gauze envelope by a transparent cylinder of glass, properly annealed, sufficiently strong, and protected as well as possible against blows from the exterior.

2nd. To withdraw the flame as much as possible from the influence of external currents, a result that has been partially attained by the adoption of glass cylinders, and completed more or less perfectly by arranging that the supply of fresh air, and the escape of the products of combustion, shall take place at certain given points, while they form, at the same time, brisk currents that are not too easily deranged by the movements of the external air.

3rd. Lastly, to diminish the causes which tend to heat the wire-gauze by arranging that the air which enters the lamp comes in contact with the flame as soon as possible, in order that, if this air is inflammable, it may burn immediately on its arrival, and thus

the body of the lamp is not filled with flame, but only with the products of combustion which are already extinguished.

These are the conditions which ought to be fulfilled if we would correct, or lessen, the imperfections pointed out in the two preceding paragraphs. They may be re-stated as follows: *deficiency of light, dangers due to the external currents, dangers arising from the gauze being unduly heated.*

Amongst all the lamps we have named, which respond more or less completely to the requirements set forth, and some of which have been intended to realize certain additional advantages of secondary importance, the lamp of M. Mueseler, of Liége, is the one that has been most generally adopted in practice, and more particularly in Belgium.

It has been considered to be so satisfactory that the Belgian government have made its use obligatory in fiery mines; but at the same time it is only in the Liége basin that it has been generally adopted up till this time.*

The Mueseler lamp is represented in figure 479. Its general form and size are similar to those of the Davy lamp; but it is somewhat heavier, more expensive at first, and costs more afterwards for repairs; and this circumstance, although of secondary importance, has doubtless militated against its more extensive employment.

As compared with the ordinary Davy lamp, the Mueseler lamp presents the following differences:

1st. The employment of a glass.

2nd. The employment of a thin sheet-iron chimney, widening suitably towards the bottom, placed in the centre of the wire-gauze directly above the flame, and at a distance above the flame that can be regulated at pleasure by raising or lowering it in the ring that grasps it.

3rd. The employment of a horizontal diaphragm of wire-gauze having the ring which holds the chimney in its centre.

By means of these arrangements the air enters laterally through the wire-gauze cylinder, descends through the wire-gauze diaphragm,

* This lamp is beginning to attract more attention in England and Wales, and has been adopted recently in several large collieries. 1880.—*Translators.*

and reaches the flame, then ascends through the chimney, and escapes through the upper part of the wire-gauze cylinder.

Made in this manner, this lamp has the following properties:

It gives a better light than the Davy lamp.

It is withdrawn almost completely from the influence of currents, the most rapid of which hardly cause any disturbance of the flame.

When placed in an explosive mixture the combustion is confined to the space below the horizontal diaphragm, and can with great difficulty only be propagated to the space above it.

The hot gases resulting from the process of combustion fill the central chimney, and are extinguished before reaching its top.

In consequence of the two last properties the flame is not propagated either through the diaphragm or through the chimney, and the gauze cylinder, therefore, never becomes heated to redness.

Such are the *very eminent* advantages of this lamp.

Its principal drawback, which some of its partisans regard as a good quality, and describe as its *exquisite sensibility*, is what we should call its *excess of sensibility;* namely, the extreme facility with which its light is extinguished, or tends to become so under various circumstances.

Thus it may be extinguished if the lamp is held in a swiftly-ascending current, like that which is encountered in climbing down pits by ladders, when these pits act as upcasts, contrary to the rules for a proper distribution of the air. This arises from the fact that the ascending current reverses the movement of the air in the lamp, or stops its flow, and cuts off the supply of fresh air.

It is also extinguished if it is placed in an inclined position, so that the whole of the products of combustion do not enter the chimney. Part of these products then mix with the air coming to supply the flame, and produce a mixture unable to sustain combustion, so that the flame is extinguished.

Extinction may again take place when the lamp is held vertically if the air becomes explosive, or so nearly explosive that its flame fills the glass, or that the cap expands itself very much. In the latter case the chimney may be no longer able to receive the whole of the products of combustion, and part of them flow under

its lip and mix with the air entering the lamp, and produce the effects just mentioned.

It is in the last case that the admirers of this lamp speak of its exquisite sensibility, in consequence of its liability to be extinguished as soon as the atmosphere becomes explosive.

But if this lamp really possesses the qualities claimed on its behalf, if its gauze cannot be made red-hot, and if the external currents of air produce no effect upon it, it would be better that it *should not go out*, and that the workman should merely be warned of the presence of gas, and that, if he had to withdraw, his lamp should still go on burning to show him the way.

If, however, the facility of extinction in the last case is to be regarded as a good quality, it is none the less an inconvenience in the two first cases.

Perhaps this inconvenience might be remedied if, instead of placing the glass directly on the top of the lamp, a small pedestal were placed beneath it, having a fine metallic gauze, or a double gauze, round about its periphery. This would be the same arrangement as that of Combes' lamp, but with this difference, that the gauze would be less easily soiled and more easily cleaned than the two horizontal circles of gauze by which the air is admitted to the latter lamp.

Nevertheless, even in its present form, the Mueseler lamp has already done good service. It is certainly safer than a *badly-handled* Davy lamp, but as careless handling is too much to be feared on the part of workmen accustomed to danger, who are often also very rash, we believe that the Mueseler lamp can be regarded as preferable to the Davy lamp, if not for all circumstances, at least for use in the working places exposed to danger from the presence of gas.

(607) But it must be well understood that no kind of safety-lamps, whatever may be their form, can afford proper security unless the most scrupulous and unceasing attention is paid to keeping them in thorough repair, and strict watch is kept against any infractions of the rules regarding their use. These rules should be drawn up with great detail and precision, and all

infringements should be punished with the utmost degree of severity.

By breaking these rules a workman not only exposes himself to danger, but he may possibly compromise the very existence of the mine, and, what is of far more serious importance, he risks the lives of his comrades. The enforcement of the rules in this case ought, therefore, to be made a veritable question of *public order*, and there would be no possible injustice committed if we did not confine ourselves to merely fining or expelling the guilty person, but summoned him before the public tribunals, especially if it were a second offence.

It must be also understood that the way to prevent accidents is not to adopt any particular safety-lamp, but to maintain the ventilation in such an efficient state that the safety-lamps have no occasion to have their merits tested practically. This result can be obtained, save under exceptional circumstances which no human foresight could prevent, by conforming to the rules laid down in parts 2 and 3 of this chapter.

APPENDIX.

EXPLANATION OF THE PLATES.

Plate XLI.—Figures 236 to 243.

FIG. 236.—No. **343.**—The object of this and the following figures, up to figure 253 inclusive, is to illustrate the various methods of mining described in the preceding chapters, together with the variations in detail required by the conditions of each case.

Figure 236 represents the system of working the beds of copper-slate of the Mansfeld district. Long-walls or faces 65 yards (60 metres) wide are driven, and the excavations are completely filled up with deads. As the quantity of deads is more than sufficient for this purpose, part has to be raised to the surface.

FIG. 237.—No. **343.**—This figure represents, on a larger scale, the mother-gate which serves as a starting-point for the long-walls referred to above. The mother-gate is carried wide enough to leave room for a tram-road, a return air-course, and a water-way; and the intervals between them are large enough for stowing the deads obtained in cutting down the roof in the three levels.

FIG. 238.—No. **343.**—This is a plan of part of one of the quarries of *thin beds* of stone in the neighbourhood of Paris. The method employed is called working *by artificial pillars and filling-up.* The pillars are built up by the quarrymen in regular courses, and serve to support the roof. The spaces between them are filled up by shovelling in the rubbish derived from the under-cutting and side-cutting.

FIG. 239.—No. **344.**—Plan of a quarry of *thick stone,* affording no

rubbish, and worked by driving galleries and leaving pillars which are not subsequently removed. This method is known as the *method by solid pillars*; these are arranged *quincunxially*, and the plan shows two sets of galleries at right angles to one another.

FIG. 240.—No. **344.**—Plan analogous to the preceding one, but differing in the disposition of the pillars, which is called the *chess-board* arrangement. It leaves galleries in one direction only, and this system is preferable when the deposit is intersected by a series of perpendicular faults or joints. (See the text of No. 344.)

FIGS. 241 and 242.—No. **344.**—Vertical sections in two directions of an underground quarry in the thick bed of gypsum in the neighbourhood of Paris. The pillars are arranged in chess-board fashion, as shown in figure 240.

FIG. 243.—No. **345.**—Workings in the great bed of brown hæmatite in the Moselle district. The method of working employed in the example under notice is that of driving galleries so as to leave long blocks, which are then cut out by means of a series of stalls separated by thin walls of ore, part of which is sacrificed. (See the text of No. 345.)

Plate XLII.—Figures 244 to 248.

FIG. 244.—No. **346.**—Vertical section of a salt mine at Dieuze, worked by galleries and permanent pillars.

FIGS. 245 and 246.—Exploitation of the Varangeville salt mines. The former figure represents the first phase of the working, which consists in driving a series of galleries, leaving pillars like those of the Dieuze salt mines. The galleries are driven in the lower beds of the deposit, which are pure enough to furnish rock salt.

Figure 246 refers to the second phase, in which the upper beds are excavated by a dissolving process. (See the text of No. 346.)

FIG. 247.—No. **347.**—Underground chalk-pit in the neighbourhood of Paris. The mass may be considered unlimited in all directions. The method is that of stories of superposed pillars and galleries, with a solid layer of chalk between every two successive stories. Care is taken that each pillar shall be vertically above the pillar below, and the same with the galleries, and that the thickness of the roof and the size of the pillars shall increase, and the height and width of the galleries diminish

with each successive story in depth. As a rule the workings are confined to three stories.

Fig. 248.—No. **349.**—This figure is a horizontal section of the cinnabar deposit at Almaden, including three erect masses, limited along the strike, which appear as if they would come together in depth.

Plate XLIII.—Figures 249 to 253.

Fig. 249.—No. **349.**—The figures 249 to 253 represent the method of working the Almaden deposit, which is shown in plan in figure 248.

With a few special details, the method employed is that of cross-cuts with filling-up. The vertical system (No. 317) is adopted; that is to say, the workings at one spot are carried up successively through all the slices of a story. Instead of stowing, masonry is employed, constructed with mortar made of sand and lime; and it is built up in proportion as fresh slices are attacked. In this manner a series of columns of masonry are raised up, leaving between them blocks of ore which are removed without filling-up. Some openings are left in the masonry in order to lighten it; and other openings, which are made to correspond to each other, serve as travelling roads after the empty spaces between the columns have been bridged over. (Figs. 249 A and 249 B.) Before a story is worked away a winze is sunk, either on the footwall or in the mass itself, and serves as a starting-point for overhand or underhand stopes (fig. 249 C); in this manner a slice is removed parallel to the walls, and the ground is left open for putting through the cross-cuts.

The great value of the ore, and the great firmness both of the ore and of the walls, explain and justify the employment of this method. The object of it is to remove the ore completely; but it is expensive on account of the amount of masonry which is necessary, and it would not be applicable for mining a substance of small value.

Fig. 250.—No. **351.**—Figures A, B, C represent a plan, a cross section, and a longitudinal section of the mode of working the alum shale in the Liége district.

The method employed is almost identical with the cross-cut method followed by pillar-working shown in figure 229, save that the roof is here somewhat thicker.

Fig. 251.—No. **353.**—This figure is a plan of part of a floor or story prepared for working the salt-marl of the Salzkammergut by the solvent process. First of all a series of parallel galleries are cut out, leaving be-

tween them long blocks 65 to 90 yards (60 to 80 metres) wide. Oblique drivages are then pushed out and opened out at their extremities into elliptical chambers, as shown in the figure. The chambers are formed by driving a network of small galleries leaving small pillars, which are soon eaten away by the water which is let in. These small pillars and galleries are shown in chamber M, but in the others it is supposed that the pillars have already disappeared.

FIG. 252.—No. **353.**—Vertical section and plan of one of the dissolving chambers referred to in the preceding figure. A is the winze for bringing in fresh water; B is the dam, which is gradually raised in proportion as the roof is heightened by the dissolving action of the fresh water, which touches it everywhere. As the water gradually dissolves out the salt, the earthy matters detach themselves from the roof, fall on the floor, and form a covering which protects it from the further action of the water, whilst, on the other hand, it never ceases to act on the roof, which is constantly presenting a fresh surface.

FIG. 253.—No. **353.**—This figure shows the kind of section that the sides of the dissolving chambers tend to assume theoretically, according as the continuous or discontinuous system is adopted. In the former, a constant stream of water is brought in at A, and the brine is drawn off at B, figure 252; in the latter, the chambers are repeatedly filled with water, which is drawn off when saturated.

Section AB in figure 253 refers to the continuous, and AB′ to the discontinuous process.

The first system is favourable for making the best use of the deposit; but the annual output of a chamber is much less, and in order to furnish a given output the workings must be more extensive.

Plate XLIV.—Figures 254 to 258.

FIG. 254.—No. **359.**—This and the following figures of the same plate refer to examples of open workings.

Figure 254 represents, on a very reduced scale, the mode of working an alluvial deposit forming the bottom of a valley. It shows that the stream has been turned off, and that there is a wide breast cut into steps, stopes, or benches, which is pushed on gradually up the valley. (See the text of No. 359.)

FIGS 255 and 256.—No. **360.**—These two figures refer to open workings on a horizontal seam cropping out on a hillside: in the former the

outcrop is some little way above the valley; in the latter it is near the bottom of it. (See the text of No. 360.)

FIG. 257.—No. **361.**—Mode of working an inclined seam in a flat country. The part near the outcrop is worked open-cast, and the bottom of the open quarry is connected by an inclined gallery, with underground workings on the dip side. The overburden is either thrown back, as shown in the figure, or else it is sent down into the mine for filling-up. This system, which utilizes the overburden for stowing the underground excavations, enables the workings to be carried on profitably by the open-cast method to a considerable depth.

FIG. 258.—No. **362.**—Mode of working a highly-inclined mass in a flat country. This example represents one of the slate-quarries at Angers. The method adopted for excavating the slate, and the way in which the working-places are arranged, have been described in detail in the text of No. 362. The figures 258 refer particularly to the manner in which the slate is drawn up from depths of 300 feet (80 to 100 metres) and more. This operation requires special arrangements, the object of which is to drop the box on the bottom of the pit *at the very point* where the rubbish or slate happens to lie. By this plan it is possible to avoid shifting large blocks, which would otherwise have to be split up before they could be handled, and so lead to a considerable waste.

Figure 258 A shows a carrying-rope with one end fixed to the pulley-frame, and the other to the bottom of the quarry; this latter point can be shifted at pleasure.

Figure 258 B exhibits another arrangement; the drawing-rope is joined to a second rope, of which the point of suspension and the length can be altered at pleasure, and in this way the box, which always hangs in the plane of the two ropes, can be made to drop at any given point of the bottom of the quarry.

Plate XLV.—Figures 259 to 271.

FIGS. 259 and 260.—Nos. **368** and **369.**—Figure 259 represents the ordinary peat-spade (*slade*, *turf-iron*), and figure 260 the long spade (in French *grand louchet*). This latter implement must be regarded as indispensable where peat has to be dug under water, which is the most common case. By the introduction of this long spade the whole business of turf-cutting has undergone a complete change.

FIG. 261.—No. **381.**—This figure, as well as all the remaining ones

of the same plate, and of the succeeding plates as far as the fifty-third, refer to the important subject of haulage underground. The figure represents a hook which the haulers or putters sometimes use for the purpose of letting down baskets in very steep and very crooked roads. It serves at the same time to hold them back and to guide them.

Fig. 262.—No. **381.**—This is a tub with runners, formerly employed at Saint Etienne, both for haulage and raising in the shaft.

These tubs are hardly used at all now, and are quite unsuitable except for very small quantities and short distances.

Fig. 263.—No. **382.**—This figure shows the best form of wheel-barrow.

Theoretically the load is not limited on a level road by the strength of the workman, provided that the shape of the body is such that the load is thrown as much as possible upon the axle, that the handles are sufficiently long, and the barrow-way in good order.

Fig. 264.—No. **384.**—This figure represents a very simple method of laying a railway in a mine.

This plan may be considered sufficient in most cases, and railways or tramways of some kind are indispensable in mines of any extent.

Fig. 265.—No. **386.**—A geometrical sketch showing the *special points* which are met with at the *junctions* (A and B) and *crossings* (C).

Fig. 266.—No. **386.**—Details of the construction of a crossing where two lines of rails belonging to two separate roads come together. (Point C of figure 265.)

Fig. 267.—No. **386.**—Details of the construction of points with movable switches. (Points A and B, figure 265.)

Fig. 268.—No. **386.**—Another kind of points in which movable switches are dispensed with. The waggons run without difficulty from the branch into the straight road; but in being pushed in the opposite direction they require to be slewed to the left if we wish to keep the straight road, and to the right if we wish to enter the branch.

Fig. 269 and 270.—No. **387.**—Examples of branch platforms or turn-plates, taking the place of the points and crossings of figures 265 to 268.

They are useful for crossing galleries at right angles to each other, as in workings of the bord and pillar type. The wheels must be loose on the axles.

Figure 269 represents the platform composed of a series of planks laid side by side on a timber frame.

Figure 270 represents a cast-iron turn-plate. The central hole serves to lighten it, but more than that, its raised ledge acts the part of a pivot on which the waggons can be revolved until they come opposite to the particular road into which we desire to push them.

Of course the diameter of the hole is somewhat less than the width between the rails.

Fig. 271.—No. **398.**—This figure is meant to show the relation between the radius of the curvature that can be given to a roadway, the size of the gallery, and the amount of pillar that should be cut away when we have to turn at right angles. This relation is given by the condition that the side of the gallery remains at a constant distance from the axis of the railway at the point where the bend is made. (See the text of No. 398.)

Plate XLVI.—Figures 272 to 278.

Fig. 272.—No. **407.**—This figure, and all the others of the same plate, and of the next two plates up to figure 284, represent a certain number of types of rolling stock employed in mines, each satisfying in a greater or less degree the conditions enumerated in Nos. 388 to 399.

Figure 272 in particular shows the longitudinal and transverse elevation of a small waggon, called *chien de mine* in French, and *Hund* in German. It is suitable for long, winding, and narrow galleries, like levels driven along a narrow lode.

They run upon a road formed of two lines of planks 4 to 5 inches ($0^m{\cdot}1$ to $0^m{\cdot}12$) wide, about 1 inch ($0^m{\cdot}03$) apart, lying upon cross-sleepers.

The space between them receives the guide-pin, which serves to keep the waggon on the roadway. The wheels have flat rims, and the two hind wheels are further apart than the two front ones, so as not to wear one part of the plank more than another. These waggons are filled by placing them under the hoppers of the *mills* or *passes*, into which the mineral from the stopes is thrown, and they are tipped at the *plat* or *lodge* by turning them upon the front axle.

Fig. 273.—No. **407.**—A small waggon, formerly much used, and still employed at the present day in the low workings of some mines in the Mons basin and in the north of France. It is arranged so as to be filled at the working faces and emptied at the pit bottom. The frame, which

is entirely of iron, is jointed at two points close to the front axle. The body is fixed to this axle by means of two bolts, and it simply rests on the hinder axle. We can thus raise the body by means of a handle at the back, and cause it to turn round the front axle without lifting the frame, which remains standing on the road.

FIG. 274.—No. 407.—Various forms of waggons employed in the Newcastle mines. Those most generally employed are entirely of wood, and are made very strong. They are strongly bound with iron, and do not require many repairs.

Sometimes the body is prismatic, and situated altogether above the wheels; sometimes it is pyramidal, and descends to the level of the axle.

FIG. 275 to 277.—No. 407.—Three forms of sheet-iron waggons used at Liége, at Anzin, and at Blanzy. These waggons are very well designed in all their details, especially the two last, and they are so arranged as to have the greatest possible capacity with given dimensions of length, width, and height. If they were too long or too wide they would be difficult to handle in narrow and sinuous galleries; if they were too high they would require the roof to be cut, and would become difficult to load.

Plate XLVII.—Figures 278 to 282.

FIG. 278.—No. 407.—Waggon or tub used at the Grand' Combe mines. This tub has the inconvenience common to all others of an elliptical shape, that for given dimensions of length, width, and height its capacity is less than that of rectangular waggons. It is less suitable, therefore, than the waggons of figures 275 to 277 in mines where the question of capacity is of importance in consequence of the galleries being low, narrow, or crooked. On the other hand, it is simply and solidly made, and has rendered good service in practice.

FIG. 279.—No. 407.—Mine waggon used at Saint Etienne. This waggon is also one which answers very well. It differs from the last in being less strongly constructed, and in having the flanges of its wheels flat, an arrangement which makes them suitable for running on the floor of the stalls, or on platforms at the junction of roads. The rim is often much wider than is shown in the figure.

The hooks at the sides are for enabling it to be raised in the shaft, as we shall see further on.

FIG. 280.—No. **407.**—Cabany waggon. This is almost the same as the Anzin waggon, save that the axle is bent instead of being straight. The bend enables the bottom of the waggon to be brought down lower, almost, in fact, to the level of the floor, and thus diminishes the total height for a given load. The bent axle and its journals may all be in one solid piece; and this is the strongest arrangement. The two journals may be separate pieces, so that when repairs are necessary only the parts subject to wear need to be replaced; but this method of construction would demand great precision of adjustment, and would be, as may be easily understood, less rigid and more liable to require repairs wherever the least play begins to manifest itself between the pieces.

FIG. 281.—No. **407.**—Trolley and corves of the Loire district. This system, which is little employed nowadays, was very useful when there were railways in the principal galleries only, and when the haulage between the working faces and these galleries was done by sledges.

The figure shows the system of a separate axle to each wheel, described in No. 397.

This arrangement gives rise to a large amount of dead weight, both on account of the weight of the corves and the double axles.

FIG. 282.—No. **407.**—Boat used in the Worsley mines. This system is analogous to that of the trolley in the previous figure, but the load is much heavier. (See No. 405.)

Plate XLVIII.—Figures 283 to 288.

FIG. 283.—No. **407.**—Large tub employed at Blanzy. This tub has sheet-iron sides and a wooden bottom; it is not suitable for many places on account of its height, which makes it difficult to fill, and on account of its weight, which makes it difficult to handle.

FIG. 284.—No. **407.**—Large waggon employed at the Grand' Combe mines. It carries about the same load as the preceding one, and is still heavier than it; but it is of a better shape and more compact. It is only employed in thick seams worked by adits. In the thin seams, and in those worked by pits, it is advantageously replaced by the tub shown in figure 278 of the preceding plate. Apart from the question of capacity, it is thoroughly well designed in all its details. It is not emptied by being entirely overturned like many of the lighter mine waggons, but simply by opening a door in front.

FIG. 285.—No. **407.**—The various figures numbered **285** show different forms of bearings for waggons which have wheels keyed on to the axles. These bearings are sometimes made of brass, but oftener of cast-iron. They are fixed by bolts to the frame of the waggon, and are held in place by a cover made of wood, or by an iron strap.

A. Brass bearing, with a cover of wood, held in place by two square bolts, which lie in grooves at the sides, and are tightened up by a gland and two nuts.

B. Another bearing, in which the wooden cover is replaced by an iron strap, which is screwed up tightly against the lower face of the bearing, at the same time leaving a certain amount of play between itself and the axle.

C. Cast-iron bearing with flanges, kept in place by two nuts and screwed up tightly. The nuts of the wooden cover are not screwed so tightly in order to avoid unnecessary friction.

D. Bearing for two parallel axles of the same pair of wheels in a waggon with four axles. It holds the journal of one axle and the end of the other.

FIG. 286.—No. **407.**—Patent axle for movable wheels upon fixed axles. The object of this arrangement is to cause the nave of the wheel to turn on the bearing of the fixed axle in a box, which must be constructed so as to contain a certain amount of oil for lubricating the bearings, to prevent the separation of the nave from the axle, and lastly, so as not to leak.

The oil reservoir consists of annular spaces formed in both the wheel and the axle. The washers, which close the two ends of the nave or axle-box after it has been put into the axle, and the projecting collar upon the axle, fulfil the two latter objects.

FIG. 287.—No. **407.**—The system described above is susceptible of various modifications, one of which is shown in figure 287. It is used with the Cabany waggons, with bent axles and separate journals (or journals that take off and on). Leakages of oil are prevented by a loose washer, which is placed between the nave and the collar at the end of the axle. An annular space in the nave contains the oil; it is closed with a small lid, kept shut by a spring. The journal is held in its place by a nut and jam nut, which also serve to fasten the bent axle to the body, and furthermore regulate the pressure upon the loose washer.

FIG. 288.—No. **407.**—The two figures represented in figure 288 represent the arrangements which have been designed for affording the

advantages of continuous lubrication in the case of wheels with fixed axles.

A. represents M. Evrard's system, in which the body of the axle is formed by a fixed iron tube, which receives movable journals, to which the wheels are keyed. Here we have the same advantages as with four axles. The reservoir for oil lies between the ends of the two axles, each of which occupies about one-third of the length of the tube, and the oil which escapes from it passes into the space between the axles and the tube, and thus lubricates the rubbing surfaces.

In order to facilitate the penetration of the oil along the axle, it is best to run a spiral groove along the latter.

B. is another system invented by M. G. Dubois. The two journals form a single piece, which constitutes the axle properly so-called, and they turn in the interior of a hollow casting, which forms the bearings at its two ends, and the oil reservoir in the middle. This arrangement, which in reality consists of making the two grease-boxes into one piece, is not suitable for anything but narrow gauges, such as those in mines.

It may be observed here in a general manner that every system of greasing employed on large railways can be adopted in mines, and it is well known that the number of systems is very large; but as they entail many complications requiring great attention to minutiæ, it is most customary to rest satisfied with the simplest arrangement, and to put a little grease on the axles at every journey just before the waggons are sent down.

Plate XLIX.—Figures 289 to 295.

FIG. 289.—No. **410.**—Arrangement of the roads on a self-acting incline, having three rails at the upper end, two distinct roads at the middle, where the trains pass each other, and one road at the lower end. This arrangement answers all the purpose of two distinct roads all the way, and it admits of the gallery being narrower. The points at *a* are changed by the waggons themselves without the intervention of a workman. (See the text of No. 410.)

FIG. 290.—No. **411.**—The details of Fowler's clip pulley, which is much used for self-acting inclines in England. It has the remarkable property of being able to prevent the rope from slipping in the groove, and it thus becomes possible to employ a brake on a self-acting incline even when the gear at its upper end consists only of a single pulley with a rope passing over it. This result is obtained by constructing the groove of two series of articulated pieces, which approach each other two by two,

and jam the rope between them with a force which is proportional to the pressure exercised by the rope upon the groove; and for a pulley of given diameter this pressure is itself proportional to the strain upon the rope.

FIG. 291.—No. **411.**—An arrangement whereby a resistance to the slipping of a rope on a pulley is obtained equal in amount to what it would be if the rope, instead of lying in three separate grooves, made several half-turns in one groove. (Three half-turns, according to the figure.) The advantage of this system is that the same result is obtained by it as if the rope really made three half-turns in the same groove, without the rope being subjected to such friction and wear as there would be in that case.

The rope may pass from the main to the auxiliary pulley either in a straight or in a curved manner. The first arrangement is represented in the drawing by the plain lines, the second by the dotted lines. (See the text of No. 411.)

FIG. 292.—No. **413.**—Example of the arrangement of a self-acting incline with two roads serving a number of distinct levels. It is arranged in such a way that we can pass from one or other of two level roads on to one or other of the two inclined roads, and *vice versâ.*

Although it looks complicated, it does not require anything besides points and crossings like those at A B C on figure 265. There is no new detail of construction that requires to be described. The system supposes the general inclination of the incline to be moderate. (See the text of No. 413.)

FIG. 293.—No. **413.**—Turn-plate which can be employed instead of the preceding arrangement when the waggons are light enough to be easily turned on plates. These turn-plates are not suitable unless the inclination is but slight.

FIG. 294.—No. **413.**—An arrangement for making or unmaking a landing-place at any point on an incline by lifting or replacing a rail.

FIG. 295.—No. **416.**—Example of a carriage for waggons on an inclined plane. The carriage represented in this figure is made so that it can be employed on different inclines in succession, for the purpose of conveying the products of various stopes to the level, even when the gradients vary. The figure shows how it is possible to vary the angle between the platform and the frame carrying the wheels, so that this platform always remains level, or nearly so, whatever may be the inclination. (See the text of No. 416.)

Plate L.—Figures 296 to 299.

Fig. 296.—No. **417.**—This figure, and all the others of this plate, refer to the employment of self-acting inclined planes in mines for the purpose of connecting two points whose difference of level, as compared to their horizontal distance, is such that a full waggon, descending towards the bottom of the shaft or day-level, can by the action of gravity be employed for drawing up an empty waggon at the same time.

Figure 296 represents an inclined plane with two distinct roads, and serving the landing-place at the top of the plane as well as intermediate ones.

Fig. 297.—No. **417.**—The two figures 297 A and 297 B represent, by way of example, two arrangements for working a brake that can be placed at the end of an incline.

Figure 297 A represents a windlass with a brake-wheel in the middle. The system shown in fig. 297 B may be still further simplified by not cutting away the floor to make room for the frame. It is merely necessary to place the frame which carries the brake-wheel directly on the floor, and to fasten it by means of a hook made of round iron driven firmly into a bore-hole. This arrangement is convenient for an inclined plane which serves a stall going to the rise, and requiring the brake-wheel to be shifted every two or three days. (*Industrie Minérale*, vol. i. 1856.)

Fig. 298.—No. **417.**—Plan and vertical section of a continuous-acting inclined plane having two roadways, and serving only one landing at the top. One road serves for the descending and the other for the ascending waggons.

Fig. 299.—No. **417.**—Vertical section and elevation of an inclined plane with a waggon-carriage, and a counterbalance. This arrangement, which is employed in the mines in the North of France, is arranged so that it can be used with narrow galleries, and various inclinations.

There is only one waggon-carriage, and the angle between the platform and the frame carrying the wheels can be varied, as shown in figure 295.

The counterbalance waggon runs on a narrow line of rails between those of the waggon-carriage. The former is very low, and it can pass underneath the latter where they meet.

This arrangement is well calculated to do good service in a series of level-course stalls.

When the bottom of the waggon-carriage is too low to admit of the counterbalance waggon passing under it, the rails of the latter are lowered, or those of the former are raised, as described in the text.

Plate LI.—Figures 300 to 307.

FIG. 300.—No. **417.**—A form of waggon suitable for traffic either on level roads, or on inclines of greater or less inclination.

This result is obtained by forming the frame for the wheels of two triangular cheeks, whose apices serve as the axis of suspension of the box of the waggon.

This axis is placed above the centre of gravity of the box, which thus remains vertical, whatever may be the inclination of the plane over which the wheels happen to be passing.

FIG. 301.—No. **418.**—This figure serves to show how a *blind pit* or *staple* can often be advantageously adopted instead of a system of inclined planes.

Thus a blind pit, or staple, such as A B, will bring the coal worked to the rise of the point A in a more direct way to the point B than if it descended to C on an inclined plane, and returned along the cross-measure drift to B.

FIG. 302.—No. **422.**—Figures 302 A and 302 B represent a general view and the details of a dip incline; that is to say, of an incline which instead of being self-acting is worked by a fixed engine placed at the top of the incline, since the haulage must take place in an ascending, and not in a descending sense.

Figure 302 B shows the details of a hinged platform at any intermediate landing-place, by means of which an empty waggon can be received from the descending branch of the endless rope, or a full one can be taken away by hooking it to the ascending rope.

FIG. 303.—No. **424.**—General arrangement of machinery worked by steam or by compressed air, and intended for haulage by means of two ropes. (Tail-rope system.)

The engine is nothing more nor less than an ordinary winding engine with two cylinders. But the drums, instead of being fixed on one and the same shaft, like that usually employed in a winding engine, are on two separate shafts, and each is set in motion by a system of toothed gearing. Each drum can also be rendered independent or not of the fly-wheel shaft at pleasure.

A train of waggons is attached at its front end to one of the ropes, and at its rear end to the other rope. The latter rope extends to the very end of the engine plane, and there passes round a pulley and returns to the engine.

If the train consists of full waggons it is drawn towards the shaft, and if of empties it returns towards the workings.

In the first case it is the *main rope* that pulls, and in the second it is the *tail rope*. The corresponding drum is in gear with the engine while the other is out of gear, and held lightly with a brake, in order that the rope may not become slack and loose.

FIG. 304.—No. **424**.—The two figures 304 A and 304 B are two examples of the arrangements which can be employed for putting the drums into and out of gear. This is effected by shifting the plummer-block of the spur-wheel just enough to bring its teeth into or out of connection with those of the pinion which drives it.

FIG. 305.—No. **424**.—Figure 305 is a diagram showing the arrangement of the pulley situated at the inner end of the engine plane, where the empty waggons coming from the shaft are received, and where the trains of full waggons are prepared before being drawn to the shaft. The figure assumes the existence of only one road, which divides into two at each end for the purpose of making up the trains. The main rope is in the centre of the road; that part of the tail rope between the engine and the return pulley is at one side of the engine plane, and suitably guided.

FIG. 306.—No. **424**.—The three figures 306 A, 306 B, and 306 C, are diagrams of the arrangements to be made at branch roads. The object of these arrangements is to enable a train when it arrives at a branch road either to continue along the main road or to turn into the branch road and be drawn along it to a given distance. (See the text of No. 424.)

FIG. 307.—No. **424**.—Figure 307 is the diagram of *a station*, not of a junction.

A station differs from *a junction* in this respect, that at the former point there is a siding, in which the trains of full waggons are made up, or the trains of empties are received for the purpose of being broken up. (See the text of No. 424, which describes how these operations are effected.)

Plate LII.—Figures 308 to 314.

FIG. 308.—No. **424.**—Figure 308 shows the arrangements that can be made for guiding the ropes and waggons round the curves or bends that are met with in the galleries. The higher pulley is intended to guide the tail rope, and the lower one to guide the main rope. The trains are steadied on these parts of the road by means of guide-rails.

FIG. 309.—No. **424.**—An example of an arrangement that can be made for hooking and unhooking the trains rapidly at the junctions and at stations, as well as at the bottom of the shaft and at the inner end of the engine plane. A pin is pulled out by hand, and the hinged part, which locks the hook, is kicked loose by the foot. The hook immediately opens in consequence of the tension on the rope.

FIG. 310 and 311.—No. **425.**—These two figures, and those following them as far as figure 315 of plate 53, refer to the endless chain system.

These figures show two arrangements that may be adopted for driving one or two main pulleys by means of any kind of motor. Each of these pulleys receives an endless chain which runs along two parallel roads, and passes round a return pulley at the far end.

The two chains are suspended, and one rests on the full waggons, the other on the empties. The waggons are pushed under the chains at regular intervals.

FIG. 312.—No. **426.**—The arrangement of a return pulley placed at the extremity of the double road, on which an endless chain works. This figure shows the sheave which keeps the chain for the empties at the proper height for winding on, and the system by means of which the waggons about to leave the chain are kept on the road and disengaged from the chain.

FIG. 313.—No. **426.**—The arrangement that may be made at a curve. The chain is received by a pulley, placed at a suitable height above the road. The waggon is left to itself for an instant, during which it runs round the curve, and becomes engaged with the chain again in the new direction. This result may be obtained either by means of a special workman standing at the curve, or by the action of gravity alone, by giving a slope in the proper direction to the curved part of the road.

FIG. 314.—No. **426.**—An example of junctions for an endless chain. The general plan consists in putting up a return pulley, which is driven

by the main chain, at the point where two or more lines come together. The axle of this wheel carries a bevelled wheel, which by means of some simple gearing sets in motion other pulleys, each of which in its turn becomes a driving pulley for one of the branches.

The kind of cross-way formed at the junction of the branches is laid with plates, on which both full and empty waggons are handled by men, and pushed into the roads they are intended to follow.

The various chains can be driven at velocities corresponding to the output of the districts they serve, so that the spaces between the waggons can be made nearly uniform for all the chains. This uniformity is not, however, an essential condition.

Plate LIII.—Figures 315 to 319.

Fig. 315.—No. **426.**—Example of a station on the endless chain system of figures 310 to 314, at which it is possible to add full waggons to, or take off empty ones from, the trains which are running on the main line. (See the text of No. 426.)

Fig. 316.—No. **427.**—Example of the general arrangement of the endless rope system with two roads. The system comprises a horizontal steam-engine driving a pulley with several grooves similar to that of figure 291. The boilers are close to the engine, and are set up in a kind of side chamber, formed by enlarging the gallery. The endless rope passes from the pulley on to one of the roads, and runs along it to the end, where it passes round a return pulley, which brings it on to the other road, along which it returns to the driving pulley with several grooves. From the driving pulley it also passes on to another large pulley, fixed on a movable carriage, which stretches it to the proper degree of tension by means of a weight.

Fig. 317.—No. **427.**—A special carriage or bogie placed at the front of a train, and having a seat for the conductor.

This waggon contains all the arrangements necessary for enabling the conductor to take hold of the rope moving between the rails on which his train is placed, by means of a hook, and to lift it slightly for the purpose of gripping it between two jaws—one fixed, the other movable, and both situated below the carriage. He can also release the rope in the same way when he likes, by opening the jaw; and lastly, he can apply a brake so as to pull up a moving train after the rope has been thrown off. In this way every operation required for carrying on under-

ground haulage can be performed without stopping the engine which sets the ropes in motion.

It is quite possible to have a number of empty trains travelling on one of the roads and a number of full ones travelling on the other at the same time, and in this way a considerable amount of traffic may be carried on.

FIG. 318.—No. **427.**—Various ways of constructing clips, by means of which the conductor, who sits in an empty waggon in front of a train, can seize or let go the rope at pleasure. The rope in this case also is understood to be travelling between the rails on which the train is placed.

These clips serve the same purpose as the contrivances shown in the preceding figure 317, and are perhaps more simple.

FIG. 319.—No. **428.**—The mode of attaching waggons to an endless rope when it lies on the top of them, like the endless chain, instead of passing under them. (See the text of No. 428.)

Plate LIV.—Figures 320 to 322.

FIG. 320.—No. **439.**—This figure and the two others contained in the same plate refer to a subject which, although only recently brought forward, is already well appreciated. Its importance will also become more and more realized in proportion as winding engines are made more powerful and the cost of coal becomes greater.

They represent variable expansion gearing on winding engines, which is advisable in consequence of the essentially unequal work required of them.

FIG. 320 represents M. Audemar's system of cut-off, which consists in shutting off the steam in the slide-valve chamber by a valve worked by means of a clutch, which can be moved along its axis at pleasure. This arrangement has long been known, but M. Audemar has perfected it by connecting the clutch with the reversing lever, and by arranging the gear so that a *very slight movement* of the reversing lever, making but *little* difference in the throw of the slide-valve, is sufficient to shift the clutch considerably, and so to change the degree of expansion *very much.*

FIG. 321.—No. **440.**—This figure gives an idea of M. Guichotte's system, which is founded upon that of Meyer, and consists in the employment of two superposed slide-valves.

The lower slide-valve must be regarded as an ordinary one, whilst the

initial position of the upper slide-valve may be changed so as to produce the equivalent of what is usually termed *lead.* The same arrangement which produces the change in this earlier admission produces in this case a change in the degree of expansion. (For the details see the text of No. 440.)

Fig. 322.—No. **441.**—M. Scohy's system of expansion. This system is applicable to engines which have a separate steam and exhaust valve at each end of the cylinder, and consists in cutting off the steam in the chamber of each admission valve by means of a special slide worked by an eccentric keyed on parallelly to the crank. The position of this slide is altered by means of a little hand-wheel, like the one in Meyer's gearing. (See the text of No. 441.)

It does not appear that the merits of these three systems have yet been sufficiently tested, so as to admit of an opinion being pronounced as to their respective value. They have been only recently introduced, but they appear to be spreading rapidly.

It is probable that others will be invented.

Plate LV.—Figure 323.

Fig. 323.—No. **444.**—Figure 323 and those following it, as far as 328 of Plate LX., represent winding engines, which, after having been made of various designs for a number of years past, have at last settled down to the now ordinary form of two vertical or horizontal cylinders, working the drum-shaft directly.

All the figures of these plates are drawn to a common scale of one-fiftieth of the natural size, in order that a comparison may be more easily made between the various engines.

The engine shown in figure 323 is a sixty horse-power beam-engine, with a single cylinder, and worked with high-pressure steam without either expansion or condensation.

Thirty or forty years ago this kind of engine was in high favour, and very generally adopted amongst the large mines of the Department of the Nord, and in Belgium. It was used for winding with large kibbles, which were raised and lowered very slowly.

At the present day it may be considered as quite out of date, as it is no longer suitable for the large outputs now required.

Plate LVI.—Figure 324.

Fig. 324.—No. **444.**—Example of a winding engine with a single horizontal cylinder and toothed gearing.

This engine has three advantages over the preceding one; namely, it is much less costly, the outlay required for erecting it is smaller, and it can run at a higher speed. Many engines of this kind were erected until it became necessary to increase the outputs, when engines with two cylinders were introduced. The latter can be driven much more quickly, and, what is of even more consequence, they are easily handled, as they have no dead-point. These advantages, together with the employment of guides in the shaft, have permitted the whole of the operations connected with winding to be greatly accelerated.

Plate LVII.—Figure 325.

FIG. 325.—No. 444.—Winding engine with two horizontal cylinders, and without toothed gearing. Constructed by M. Quillacq.

This engine may be considered as a type presenting all the principal advantages that have been aimed at in constructing winding engines, during the last twenty years, with the view of increasing the output.

It is besides very well arranged, so that the engine-man may have all parts of the machine conveniently at hand and under his eyes, and especially the various handles for working it—the steam-valve, the reversing lever, the steam-brake, &c.

He can also have the pulleys and the top of the shaft in sight.

Engines of this type are already very common, and they are becoming more and more extensively employed.

They should be perfected by the employment of variable expansion gear.

Plate LVIII.—Figure 326.

FIG. 326.—No. 444.—This figure and that of the following plate represent a type of engine which possesses the same essential properties as that of the last plate.

The principal difference between them is to be found in the fact that the cylinders in this case are vertical, instead of horizontal as they were in the former case.

The vertical type is being more commonly introduced at the present day than the horizontal one perhaps; but the question as to which of them is to be preferred is still a matter of controversy amongst a large number of mining engineers.

Each of the types has its advantages and its disadvantages.

In the first place as regards the mode of their construction, the vertical engines are often held to be better than horizontal ones, since

the cylinders of the latter are apt to become oval by wear; and the rest of their parts also wear unequally, inasmuch as the weight of the pieces, and the forces acting upon them inside the cylinder, tend habitually to press unequally and unsymmetrically upon the surfaces which support them.

This fault is, perhaps, more *theoretical* than practical when proper care has been taken to fit the parts with precision, to make the wearing surfaces of hard metal, more especially of steel, and to make all the surfaces that are in contact with each other as large as possible. The last arrangement, while *not* altering the *total pressure* on a surface, *nor the total intensity* of its friction, or of the *work expended upon it*, reduces the friction *per unit of surface*, and consequently *diminishes the amount of wear.*

Again, we might find fault with horizontal engines on account of the manner in which the cylinders are usually fixed to the bed-plate, as being more liable to strain in consequence of the unequal expansions of various parts caused by the more or less elevated temperatures which the steam imparts to them.

A further objection is that they take up so much room in horizontal projection. But the ground round about the mouth of a shaft is not generally sold by the square yard, and therefore the last complaint is of little importance. This greater horizontal extension, which brings every part within sight and easy reach of the engine-man, seems, on the contrary, to be rather an advantage than otherwise, and to constitute a decided superiority over vertical engines, because the latter have the whole of their gear superposed, so to say, less easily seen, and out of the reach of the engine-man unless he is continually going up and down. Besides being more convenient, the horizontal position also makes the engine more stable.

One of the advantages claimed for vertical engines is that they permit of the pulley-wheels being placed on a higher level, and consequently for a given distance of the pulley-frame from the engine, and for a given height of frame, the angle included between the part of the rope hanging in the shaft and the part of it going towards the drums is greater than in the case of horizontal engines. It is supposed that the angle at which the rope is bent is diminished, and consequently its strain is lessened. This supposition scarcely appears to us to be quite correct; the strain in the rope due to bending is greater or less, according as the radius of the pulley is larger or smaller, and not according as the arc which it occupies on the circumference is longer or shorter. The high position of the drums does not therefore save the rope, and it diminishes the stability of the pulley-frame since it increases the horizontal component which tends to overturn it. The real advantage

of the vertical engine is that it brings the engine-man nearer the pit, and raises him to a better level for seeing the landing-places.

It has been remarked that the same advantage can be obtained by making the ropes of horizontal engines pass above the engine-man, the cylinders being between the drums and the shaft; but then the engine-man must turn his back either to the pit or to the drums. The arrangement is therefore a bad one, and he is besides very much exposed in case of an accidental breakage of the rope that passes over his head.

In summing up it may be said that, from a practical point of view, most of the advantages, taking them as a whole, are in favour of horizontal engines, whereas the advantage of placing the engine-man in such a position that he can best see all that goes on, and at the same time be in a favourable situation for communicating with the banksmen, lies with the vertical engine.

As the last advantage is likely to permit of a rather more rapid rate of winding, and consequently a greater output—a matter of the first importance—we are inclined to think that this consideration will gradually cause vertical engines to be preferred. This preference will besides be justified by the remark that the disadvantages of a horizontal position, considered from the point of view of unequal wear, will become more felt as the engines are built of larger sizes.

Turning from these general remarks to figure 326 again, the same essential parts will be observed as in the preceding figure. The solid connection between the driving cylinders and the drum-shaft, which is obtained by the employment of a bed-plate in the horizontal engine, is provided for in the vertical engine by having two strong cast-iron girders, supported by pillars of the same material, and forming a frame upon which the drum-shaft rests. Each cylinder and the adjacent pillars rest upon a special block of masonry, which constitutes their foundation.

Plate LIX.—Figure 327.

FIG. 327.—No. **444**.—This figure represents a vertical engine with two cylinders, which is very similar to the one shown in the preceding figure as far as its general arrangements are concerned; and, consequently, it gives rise to the same general observations.

The engine represented in figure 327 differs from the preceding one principally as regards the way in which the pistons and the drum-shaft are connected. In this case the true sole-plate for each cylinder is the cast-iron frame, which carries one of the bearings of the drum-shaft. The cylinder is connected to, and, it might almost be said, suspended from this frame by two tie-rods, which at the same time constitute the guides.

The cylinder is placed in a kind of narrow chamber between the two thick walls which serve as a foundation to the frame.

This arrangement appears to us to be a better one than that of figure 326, and consequently better adapted to very large engines. On the other hand, it hides an important part of the engine from the view of the engine-man.

Plate LX.—Figures 328 to 330.

FIG. 328.—No. **444.**—The three preceding plates represent the three types of winding engines that are most in favour with engineers at the present day. It may be said that every engine erected in France and Belgium, and intended to serve for raising large outputs, belongs to one or other of these three types, which unite many advantages in themselves. Figure 328 is given as a specimen of further modifications that are being tried in various directions by some engineers, who do not consider that winding engines are yet as perfect as they may be made, nor that they have arrived at their final stage of completeness.

We know that there is room for considerable improvement as regards consumption of fuel by employing expansion, and even returning to condensation.

The advantage aimed at in figure 328 has no reference to the mode of employing the steam. It is less radical, and has no other object than to lessen the wear of the winding ropes. (See the text of No. 444.)

We know that, in the case of ordinary engines, when the drums are on the same shaft, the ropes do not wear equally. The one that winds *over the drum*, that is to say, that bends on the drum *in the same sense* as on the pulley, usually lasts longer than the one that winds *under the drum*, or is compelled to wind on the drum *in a contrary sense* to that in which it passes over the pulley. The difference is easily understood.

In the engine here represented the inventor, M. Colson, avoids this disadvantage by having two drums on different shafts revolving in contrary directions. Both ropes can thus unwind from above; for, in consequence of the shafts revolving in opposite senses, one rope must unwind while the other is wound on to its drum.

M. Colson has furthermore taken advantage of the fact that the two drum-shafts rotate in opposite directions for guiding the two piston-rods of the steam cylinders.

For this purpose the two cylinders are placed symmetrically between the two drums; their piston-rods carry a cross-piece in the form of a T, which is exactly of the same length as the distance between the centres of the drum-shafts. To each end of this cross-piece is hung a connecting-

rod attached to a crank. The cranks are keyed on to the drum-shaft in a symmetrical position, which they always retain while revolving.

This arrangement obviously assures the horizontality of the T-piece and the vertical movement of its central point.

This mechanical combination is not, however, new; for it is shown in the atlas of *La Richesse Minérale* (plate 39 and plate 41) in figures which give both the general plan and the details of a rotary winding engine in actual use.

It does not seem to us that M. Colson's engine deserves to be preferred to those in use at the present day. The advantage which he seeks is of secondary importance, and does not compensate for the somewhat greater complication of the engine, and for a less perfect system of guiding the piston-rod which renders it more subject to vibrations, especially in the case of very large engines.

FIG. 329.—No. **446**.—Figure 329 represents a horizontal drum for round ropes. The object of its slightly conical form is not to compensate the varying weight of the rope, for which purpose it would be quite inadequate, but simply to make the coils keep close together.

The little winch for regulating the exact length of the rope is also shown, and the arrangement for preventing its being bent at too sharp an angle when passing from the winch on to the drum.

FIG. 330.—No. **446**.—Drum or *reel* for a flat rope. This figure shows one way of fastening the rope to the drum. It shows further how the drum may be made to run loose on the shaft, or not, at pleasure. This arrangement need only be adopted for one of the drums, whilst the other is keyed on permanently.

The consequence is that the relative position of the two drums can be shifted for the purpose of altering the lengths of the two ropes, either once for all, or at any time when it may be necessary, in the course of a day's work, to commence winding from another onsetting place.

Plate LXI.—Figures 331 to 336.

FIG. 331.—No. **446**.—Centre piece of a drum showing how it may be set tight or loose on the shaft at pleasure. It varies but slightly from the arrangement shown in figure 330 of the preceding plate.

FIG. 332.—No. **446**.—Another example of a drum or reel for a flat rope, showing a method of fastening the rope different from that of figure 330. (See the text of No. 446 for the figures 330 to 332.)

FIG. 333A and 333B.—No. **449.**—Geometrical figures for demonstrating how a chain made of round iron of a certain diameter may be of a varying weight per fathom, increasing up to a certain limit as the length of the links decreases. (See the text of No. 449.)

FIG. 334.—No. **451.**—Diagram showing the two ends of a *tapering rope*, *i.e.* one gradually diminishing in section, which satisfies the condition that there is the same strain on it per unit of section at every point, when the weight of the rope itself is taken into account in calculating this strain. (See the theory in No. 451.)

FIGS. 335A and 335B.—No. **453.**—Diagrams for explaining the theory of chain counterbalances, employed for regulating the varying resistances which have to be overcome by a winding engine with a round rope.

Figure A represents the chain at the beginning of an operation when the cage is at the bottom of the shaft; the entire weight of the chain is now supported by the rope, and it acts *as a power*, because it pulls on the rope as it is lowered.

Figure B shows the whole of the counterbalance chain hanging from the fixed point half-way up the compartment in which it works. This is its position when the cages or kibbles meet.

As the full kibble approaches the surface, the chain gradually takes up its original position, as shown in figure A, and is then acting as a resistance, because it is being drawn up. (See the text of No. 453.)

FIG. 336.—No. **453.**—Another means of regulating the strain on the winding engine, and one which is often employed instead of a chain counterbalance in mines of the north of England. The *constant* weight of a waggon running on *a varying incline* produces the same effect as, or one similar to, that of the *varying length* of the part of the chain counterbalance supported by the rope. (See the text of No. 453.)

Plate LXII.—Figures 337 to 345.

FIG. 337.—No. **454.**—This figure, and the following ones, up to figure 343 inclusive, refer to the theory of using reels and flat ropes for regulating the varying resistances which have to be overcome by a winding engine.

The theory set forth in the text (Nos. 454 and 455) is only approximative, not only because the effect of the inertia of the cages is neglected (and in fact this effect is very small), but also, and more particularly, because the calculations are made on the supposition that the ropes are of

uniform section; this is not the case in deep pits, for which tapering ropes become more and more requisite as the depth increases, and finally indispensable for very great depths.

It is best to consider an average section while discussing the question, so as to avoid very complicated calculations; but at the same time it must be understood that the results of this calculation are only approximate.

Figure 337 gives the general outline of the curve constructed by taking as abscissa the number (m) of revolutions of the shaft after the meeting of the cages, and as ordinate the value ($M - Q\rho$) of the variation of the mean moment of the power applied to the winding engine.

FIGS. 338 to 342.—NOS. **454** to **458.**—The figures represent the same geometrical locus drawn according to different hypotheses.

Figure 338 is drawn on the supposition that the variation of the mean moment shall be *nil* at the point of arrival as well as at the meeting-place, and this involves its being *nil* also on starting.

The quantity ρ_0^2 put down on the figure is the square of the mean radius of the coils, that is to say, the radius common to both coils at the meeting-place.

In figure 339 the condition is laid down that the initial and final variations of the mean moment, which are always equal and contrary in sign, shall be equal to the absolute value of the maximum assumed by this quantity during the entire duration of an operation.

It is requisite, therefore, that the length CC′ should be equal to AA′ (fig. 339). From this we deduce the relation between OA, OB and OC, put down on the figure, and a value slightly greater than the preceding one for the mean radius of the coil.

Figure 340 refers to the case in which theory has led to values of the mean or the minimum radius which are too small and practically inadmissible, and where it is consequently necessary to take a larger value. The distance OB is reduced in proportion as this radius increases, and the figure is drawn under the hypothesis that this distance has become *nil*. The variable $M - Q\rho$ ceases to furnish a maximum. The geometrical locus becomes tangent to the line of the abscissas at the origin, and the curvature there is *nil*, because the derivative of the second order is *nil* at the same time as that of the first order.

Figure 341 is any curve corresponding to a value of the mean radius exceeding the quantity ρ_2 of the preceding figure.

Figure 342 shows how the load may be rendered regular by means of chain counterbalances, when it is no longer possible to effect this by applying the theory of Nos. 454 and 455, in consequence of this theory leading to values of ρ that are too small.

The geometrical locus $a'OA'$ having been drawn, we endeavour to find by repeated trials a straight line $OC''A''$, which will give $C'C''$ equal to $A'A''$; then if we draw the straight line AA''_1, placed symmetrically with regard to the axis of the abscissas, we have the straight line representing the moments of the strains that should be exerted by the chain counter-balance during an operation.

FIG. 343.—No. **459.**—This figure shows that by having a suitable taper, and a proper distance between the successive coils, it is possible to obtain the same regularization as with reels and flat ropes.

FIG. 344.—No. **459.**—Example of a drum which is conical for the first coils of the rope wound on, and for the last coils wound off. These correspond to the starting of the full cage, and the arrival of the empty one at the onsetting place; *i.e.* the beginning and the end of an operation. The rest of the drum is cylindrical, for the middle part of the operation of winding.

FIG. 345.—No. **459.**—This figure explains the reason of the arrangement of the preceding figure, from the fact that the form of the geometrical locus determined by theory shows that it is especially towards the beginning and end of the operation that the quantity $M - Q\rho$ varies with increasing rapidity. It is, therefore, at these points that it is most important to regulate the load, whilst towards the middle of an operation, near the point of inflexion of the geometrical locus, this quantity varies in an almost uniform manner.

The combination in figure 344 consists in adopting a conical form from A_1' to D' and from D to A', and in substituting between D and D' the straight line $D'OD$ for the curve. (For the whole of the figures shown in Plate LXII., see the theories set forth in Nos. 454 to 459.)

Plate LXIII.—Figures 346 and 347.

FIG. 346.—No. **460.**—The various figures numbered 346 are easily understood at the first glance. They represent various methods, other than the splices referred to in No. 460, which may be employed for joining pieces of ropes, or for fastening on the chains (*leaders*) to which the kibbles or cages are attached.

FIG. 347.—No. **461.**—The three figures 347 give examples of the pulleys, or *sheaves*, over which the ropes pass in going from the drum to

the shaft. Two of the pulleys shown are intended for flat ropes; one has cast-iron, the other wrought-iron, arms or spokes.

The third is intended for a round rope. The rim is made up of a number of pieces of wood *on end*, that is to say, with the fibres in line with the radii of the pulley. The employment of wooden rims, though rarely met with, is advisable, because they protect wire ropes, which are apt to be chafed against a metallic rim, especially if there are any very sudden variations of speed, causing the rope to slip to a certain extent.

Plate LXIV.—Figure 348.

FIG. 348.—No. **461.**—Figure 348 gives an example of the arrangements which may be made for fixing the pulleys above the top of the pit. The framework shown in this figure, and known by the various names of pulley-frame, pit-gear, head-stocks, head-gear, pit-head frame, poppet-heads, consists simply of two half-trusses of triangular form. This shape is a very stable one, and the two halves are properly braced together, both in their own planes and from one to the other.

Notice should be taken of the arrangement adopted for carrying the axis of the pulleys to the greatest possible height with a given height of the frame. The guides or conductors are made of wire-rope. The mineral is extracted by tubs, four of which are drawn up at once by means of a stirrup running on the conductors. (See the text of Nos. 461 to 463.)

Plate LXV.—Figures 349 and 350.

FIG. 349.—No. **461.**—This figure, like the preceding one, is an example of a pit-head frame for carrying the pulleys of a winding shaft. This system is more complicated than that of figure 348. It would be suitable for a winding shaft where larger weights had to be raised.

FIG. 350.—No. **461.**—This figure represents a tower of masonry, with suitable openings for giving access to the pit, instead of the framework of the two preceding figures.

This system is particularly suitable for countries where wood is scarce and dear, and especially for southern countries where the ordinary timber pit-head frames are rapidly destroyed from the effects of the climate.

By combining the use of masonry with that of iron girders for carrying the pulleys, as shown in figure 350, we have, it is true, a system which is more expensive originally than ordinary head-gear, but one

which will last indefinitely, and cost scarcely anything for repairs if properly erected.

It will often be advisable to adopt this system in preference to the ordinary timber framework.

Plate LXVI.—Figure 351.

FIG. 351.—No. **461.**—This figure differs from those of the two preceding plates by the head-gear being constructed entirely of metal. This method of construction is generally more costly than a timber framework; but, like the masonry tower, it has the advantage of being much more durable, and of costing less for repairs. Compared with the tower, it has the advantage of leaving the top of the shaft much more free. It may be carried up to any height without our being limited, as in the case of timber, by the length of the balks. Looking at the increasing scarcity and cost of timber, and the necessity of constructing pulley-frames of greater strength in proportion to the increased depths and speed of winding, it is probable that the use of iron pit-head gear is likely in time to extend very considerably.

The proper dimensions for the different parts of a work of this kind can be calculated precisely without difficulty, and we have here an interesting subject of study for engineers.

The type represented in figure 351 is pretty satisfactory. However, it would appear as if more stability would have been obtained by giving the structure a wider footing, and connecting the uprights by a firmer set of braces.

Plate LXVII.—Figures 352 to 355.

FIG. 352.—No. **462.**—This figure, and the following ones of the same plate, furnish some examples of arrangements for *landing* kibbles or skips at the surface.

Figure 352 represents the system formerly adopted in the Mons district, where large kibbles or corves were used, containing 52 to 55 bushels (19 to 20 hectolitres). Nowadays these have been replaced almost universally by cages with conductors.

FIG. 353.—No. **462.**—We have here a plan and a section showing the details of a system for throwing a little windlass in or out of gear with the winding machinery. The little windlass served for lifting up the kibble and tipping it completely over. Sometimes, also, the windlass

was worked by hand. This operation of emptying a kibble was carried on during the ascent of the next kibble.

Figure 352 shows the rope from this windlass, and the position of the kibble when turned completely over. The kibble was then lowered to the edge of the pit by a brake, and the rope being then completely unwound, was all ready to be wound up again as soon as the windlass was thrown into gear, no matter which way the engine was moving.

FIG. 354.—No. **463.**—Figures 354 A, 354 B, 354 C, and 354 C′ represent arrangements which may be looked upon as varieties of figure 352.

In figure A a chain fixed to part of the frame can be hooked into a ring at the bottom of the kibble, and cause it to empty itself at a given point when the winding-engine is reversed.

This arrangement allows the kibble to remain always fixed to the chains at the end of the winding-rope.

Figure B, which is analogous to the preceding ones, represents an arrangement which is frequently used in working mineral veins. The top of the pit is closed by a cover with an opening for the chain to pass through. The opening is arranged, as will be seen further on in figure 378, so as to act as a safety-catch in case the chain should break. By means of a short piece of chain, arranged as in the preceding figure, the kibble is easily made to empty its contents into the tram-waggon at the mouth of the shaft.

In figure C the shaft is supposed to be inclined, and the *skips* are provided with two sets of pivots or rollers sliding between the guides. These skips also are emptied without being unhooked from the chain.

The details of the arrangement are shown in figure 354 C′. When the engine is reversed the bottom rollers are lowered on to catches; then the upper ones pass freely through cuts in the guides, and the skip drops into the position shown in the figure. As soon as it is emptied it is drawn up and then lowered, whilst the catches are held back by means of a handle.

FIG. 355.—No. **463.**—The three figures show a plan, section, and elevation of an arrangement which has been employed with advantage for landing tubs on wheels, or trams, raised in closely-cased compartments of the shaft.

Each compartment can be closed by a cover on wheels, which cannot be moved without acting on a gate protecting the front of the compartment. Everything is so arranged that the gate is raised when the cover is pushed over the shaft in order to land the waggon which has been drawn up.

The workmen are thus protected from any danger of falling into the shaft, because each compartment is always fenced either by the gate or the cover.

Plate LXVIII.—Figures 356 to 358.

FIG. 356.—No. **464**.—Double-decked winding-cage, carrying four tubs, two on each deck. The two tubs on a deck are placed *end to end*, which is a more convenient arrangement for running them off and on than if they were *side by side*. The figure also shows a very simple arrangement for keeping the tubs in their places in the cage.

FIG. 357.—No. **464**.—Another winding-cage for drawing up the same number of tubs as the preceding one. It has four decks instead of two. This modification may be necessary if the section of the pit is not sufficiently large. It then becomes necessary, in order to avoid too great a delay in landing, to provide two landings, which serve successively for the first and third decks and for the second and fourth.

FIG. 358.—No. **464**.—Lift or hoist for sending the tubs from one floor to another if the landing-place is double. These lifts may be single-acting with a counterpoise, as shown in the figure, or else double-acting. They serve to lower the full waggons received at the top floor to the bottom landing, which is the proper level of the landing place, and to lift up the empties which have to be run on to the upper deck of the cage.

Plate LXIX.—Figures 359 to 362.

FIG. 359.—No. **464**.—Lift analogous to that of the preceding figure, but with this difference, that instead of being worked by the banksman, or by special workmen if necessary, it is actuated by the winding-engine. For this purpose there is a small pinion keyed to the shaft of one of the pulleys, and it gears into a spur-wheel which should make *one revolution only during the whole time that the pulley is occupied in raising a cage*. A crank is keyed to the shaft of this spur-wheel, and, by means of a rope, it slowly lowers and then raises the lift. By giving the rope a little extra length there is an interval of repose at the bottom which allows time for drawing out the full tub that has been lowered and running in an empty one to be raised.

FIGS. 360 and 361.—No. **464**.—These figures represent arrangements which can be adopted at onsetting places for attending to the two decks, or even four decks at once, without moving the cage, which is an indispensable condition for rapid winding.

FIG. 362.—No. **464.**—Arrangement of keeps or fangs, which can be kept open or shut at pleasure during the ascent of the cages. It is easy to see that if the keeps are shut the cage opens them in passing up, and that they are shut again automatically by suitable counterpoises, so as to receive the cage when the winding engine is reversed.

Plate LXX.—Figures 363 to 367.

FIG. 363.—No. **464.**—Arrangement of keeps with bolts, fulfilling the same purpose as the keeps of the preceding figure. There is this difference, however, that their natural position is open, and one of the banksmen has to shut them specially when the cage is lowered upon them.

FIG. 364.—No. **464.**—Another system of keeps, or fangs, which are always shut, save when the banksman holds them open by hand, so as to allow the cages to be lowered when the empty tubs have been run in.

FIGS. 365 and 366.—No. **471.**—Examples of various arrangements for steam-brakes. They ought to be powerful enough to stop the engine completely *under all circumstances.*

They are always tight while the engine is stopping, and they should not be loosened by anyone except the engine-man, and only then at the moment the engine is started. (See the text of No. 471.)

FIG. 367.—No. **472.**—Diagram showing how a rope may be made to pass through any given point. (See the text of No. 472.)

Plate LXXI.—Figures 368 to 374.

FIG. 368.—No. **472.**—This figure represents movable guiding sheaves which cause the rope to coil regularly round the cage or drum of a horse-whim. (See the text of No. 472.)

FIG. 369.—No. **473.**—This figure represents a spring placed under the bearings of the pulley, as proposed by M. Guibal. The chief object of this contrivance is to save the rope from too sudden a strain when it takes its load.

FIG. 370.—No. **473.**—Sundry springs which are occasionally placed between the end of the rope and the cage. This arrangement is more especially likely to be of use with wire ropes. The object in view, as in the case of M. Guibal's spring bearing, is to avoid straining the rope too

suddenly when the engine is started. This object is not so well fulfilled as with M. Guibal's arrangement, because the spring at the end of the rope counteracts only the effect of the inertia of the cage, and not that of the inertia of the rope.

Fig. 371.—No. **474**.—Indicators for showing the position of the cage in the shaft at any moment, and for ringing a bell to warn the engine-man that the cage is approaching the surface, and that he ought to slacken speed.

Fig. 372.—No. **474**.—Detaching-hook for liberating the cage from the rope, if the cage is drawn up too high through the engine-man's inattention, and is likely to be wound over the pulley. The mechanism works much in the same way as that of an ordinary pile-driving machine. (See the text of No. 474.)

Fig. 373.—No. **474**.—Another detaching arrangement, which is only applicable, however, where flat ropes are used, and where the *leader* is a piece of flat chain like that shown in the figure, which does not twist round.

There are a great many contrivances for preventing overwinding, differing both as regards the mechanism brought into play, and the exact functions which this mechanism has to perform. (See the text of No. 474.)

Fig. 374.—No. **476**.—This figure and those of the following plate represent different systems of safety-catches. The arrangement shown in figure 374 is known as Fontaine's safety-cage, from the name of the inventor.

This safety-cage is one of the commonest in use, although its mode of action does not seem so satisfactory as that of some other inventions. (See the text of Nos. 475 and 476.)

Plate LXXII.—Figures 375 to 378.

Figs. 375 to 377.—No. **476**.—The three figures represent different kinds of safety-catches; their mode of action will be understood from a mere inspection of the figures.

The principle of these safety-catches, like that of Fontaine's safety-cage described above, consists in fixing between the rope and the cage a set of springs, which open if the rope breaks, and thereby drive claws into the guides along which the cage is moving.

The three safety-catches shown here differ from each other, and from

Fontaine's mechanism, simply by the arrangement of the springs, and by the mode of action of the claws worked by them.

The figures themselves are quite sufficient to explain the arrangement of the springs and the manner in which the catches act. (See the text of Nos. 475 and 476.)

Fig. 378.—No. **476.**—Catch which is only applicable when chains are employed. The chain at the top of the shaft passes through an oblong slit, on one side of which there is a small shutter turning upon a hinge. This is lifted up by the links which are not in the plane of the slit as they pass up.

If the chain breaks, the last link which has lifted up the shutter closes it as it falls, and is at once stopped. It is evident that this contrivance serves only *for the chain of the ascending kibble*, and when the breakage takes place *between the engine and the top of the shaft.*

Plate LXXIII.—Figures 379 to 385.

Fig. 379.—No. **481.**—This and the following figures of this and the next plate refer to a question which is apparently very simple; but which is nevertheless of considerable importance in the case of very deep mines with a large output, where a large staff is consequently requisite. This question is that of the means to be employed for enabling the men to descend into mines and ascend from them. Figure 379 represents an ordinary *ladder-road.* However simple the matter may appear, it is nevertheless one which requires to be studied with care, and a ladder-way should be put in under the best possible conditions, because the influence which it exerts on the daily work of men, though not always apparent, is none the less real and unceasing. (See the text of No. 481.)

Figs. 380 and 381.—No. **485.**—Mechanical ladder called *Fahrkunst* in Germany, and *man-engine* in England. The two figures represent the first man-engines erected in the Hartz. They consist of two rods having a reciprocating motion in opposite directions, and provided with a series of steps and handles which are opposite to each other at the dead points. According as a man wishes to go up or down, he steps on to the little platform which is *about to ascend*, or on to the one which is *about to descend.* The two man-engines differ from each other, inasmuch as the rods in one case are made of wood, and in the other they are composed of two wire-ropes suitably braced together.

Figure 381 shows how the latter kind of rods are balanced at intervals for the purpose of diminishing the strain on the parts above.

Fig. 382.—No. **485.**—Single-rod man-engine with fixed platforms. This arrangement is common in England. The capabilities of the single-rod and double-rod machines are different, and we must refer to the text of No. 486 for an account of them.

Fig. 383.—No. **486.**—Geometrical figure which serves to explain the special properties of the double-rod and single-rod man-engines, and to establish the fact that the single-rod machine lowers the men with a smaller mean velocity; but sends down a larger number in a given time on account of the greater number of strokes which may be made per minute. (See the text of No. 486.)

Fig. 384.—No. **488.**—Geometrical representation of the section of a tapering rope A and a tapering man-engine rod B. The two sections A and B show that the law of increase of section is much more rapid for the rope than for the rod; so that the practical difficulties of working at great depths are much more marked in winding machinery than in man-engines.

Fig. 385.—No. **490.**—Sketch showing the arrangement which may be employed for imparting a *considerable* reciprocating motion to two rods which have to be *close together*, by means of a connecting-rod and two bell-cranks, or bobs, coupled together.

Plate LXXIV.—Figures 386 to 388.

Fig. 386.—No. **491.**—Machine called a *Warocquère*, from M. Warocqué, the inventor, who was the first to put one up. In principle it differs from the man-engines just described, merely from its being constructed on a larger scale, so as to be able to receive several men at once on each step. The machine is driven by a double-acting steam-engine, which acts on one rod directly, and on the other by means of a hydraulic balance. (See the text of No. 491.)

Figs. 387 and 388.—No. **492.**—These figures represent two other machines intended to fulfil the same purpose as the Warocquère of figure 386.

Figure 387 differs first of all by having the double-acting engine replaced by two single-acting engines, each working one rod, and both being firmly connected together by a chain passing over a return pulley; it differs also inasmuch as the hydraulic balance is not used, and the rods are made of iron in place of timber.

Figure 388 differs from the preceding one by the means employed for connecting the rods. The pulley and chain are replaced by a pinion, which works a rack at the end of each rod. All these various arrangements are about equally good, and none of them present any marked and characteristic advantages over the others. When we compare the more simply constructed machines of the preceding plate with the Warocquère, we can hardly say that the latter is a decided step in advance. (See the text of No. 493 on this subject.)

Plate LXXV.—Figures 389 to 397.

FIG. 389.—No. **508.**—This and the following figures of the same plate refer to a very important question, and one which was little understood before M. Dumont, of Liége, wrote upon it; viz., the manner in which subsidences of the ground take place from mineral being worked underneath.

If AB is the extent along the dip of some workings in a seam which have been completely filled up afterwards, the movements in the ground consist of two fractures along the prolongations of the lines AC and BD, which extend to *any distance*, and produce a fixed *amount of subsidence* at right angles to the plane of the seam.

FIG. 390.—No. **509.**—Figure which serves to explain why the fractures just mentioned take place perpendicularly to the stratification, and not along vertical lines. (See the text of No. 509.)

FIG. 391.—No. **510.**—This figure shows how the fractures, which began at right angles to the bedding, are transmitted in passing from one formation to a second which is resting upon it unconformably. (See the text of No. 510.)

FIG. 392.—No. **510.**—Figures 392 A and 392 B exhibit a condition of things *analogous* to that of the preceding figure, inasmuch as it supposed that the dip *varies*, although we are dealing with one and the same formation.

The geometrical locus of a *hook* plays the same part here as the plane of separation between the two unconformable formations in the preceding figure.

FIG. 393.—No. **511.**—Application of the theory explained in Nos. 508 to 510, and the corresponding figures 389 to 392, for determining the dimensions of a pillar which should be left either around a shaft, or

under buildings at the surface, in order to protect them from movements in the ground. (See the text of No. 511.)

FIG. 394.—No. **512.**—This and the following figure refer to the case where a seam worked without stowing is sufficiently thick to cause a regular falling away, instead of a gradual subsidence of the overlying strata, accompanied by a breaking up of the roof and an increase in bulk.

The increase in bulk finally becomes sufficient to fill up the cavities entirely, and the subsidence continues above this mass of broken rubbish in the same manner as has just been explained in the case of thin seams worked with stowing.

In figure 394 it is supposed that the roof is *weak*, and that the first falls have broken off along sloping lines; the consequence is that the area of the subsidence is larger than that of the workings which cause it.

FIG. 395.—No. **512.**—Figure 395 refers to the case where the rocks, on the contrary, are *very firm*, so that the roof overhangs a little; and therefore the area of subsidence is smaller than that of the workings underneath. (See the text of No. 512.)

FIG. 396.—No. **512.**—Mode of applying the theory in determining the position of a pillar which ought to be left so as to prevent any subsidence of the ground from reaching a given point of the surface, for instance, the bed of a stream.

FIG. 397.—No. **514.**—Mode of putting in bore-holes when driving towards old workings full of water. (See the text of No. 514.)

Plate LXXVI.—Figures 398 to 409.

FIG. 398.—No. **515.**—This and the following figures up to 409 explain the manner of putting in certain special structures for the purpose of keeping back water flowing into certain parts of a mine, and preventing its reaching the rest of the workings.

These structures are called *dams*, and are used for stopping shafts or drifts.

In figure 398, which represents a *straight dam*, the ground is supposed to be firm enough for the shoulder of rock round the level to be able to resist the total pressure of the water on the back of the dam.

FIG. 399.—No. **515.**—This figure represents a straight dam, in a rock which is less firm than that of the preceding figure, and which has been,

therefore, cut obliquely, so that the thrust of the dam may bear against the sides of the level.

FIG. 400.—No. 515.—*Lock dam*, which is used when the gallery to be dammed is too wide or too high for single balks of timber.

FIG. 401.—No. 515.—Example of a *spherical dam* which may be employed when the ground is not very firm, or the gallery very large, or when the pressure of water is very great. The advantage of this system is, that dams may be constructed of any desired strength, without its being necessary to employ timber of extraordinary dimensions.

FIG. 402.—No. 516.—This figure shows how a dam may be strengthened if it is thought that it is not firm enough to resist the pressure of the water.

FIG. 403.—No. 516.—Arrangements which may be adopted for carrying off the water during the progress of the work.

FIG. 404.—No. 516.—Lock dam differing from the one shown in figure 400 by the angle and position of the balks of timber. This system is intermediate between the straight dam of figure 398 and the lock dam of figure 400.

FIGS. 405 and 406.—No. 516.—These figures exhibit various details relating to two spherical dams put in according to the plan shown in figure 401. They represent the flat iron wedges for wedging up the back of the dam; the means of closing the dam, when the workmen have passed inside, either by a plug (fig. 405) or a cock (fig. 406); the use of a little curved pipe for carrying off all the air as the water rises and comes to press on the dam; the arrangements for carrying off the water while the dam is being put in.

FIGS. 407 and 408.—No. 516.—Modes of strengthening a dam in a shaft or a level.

FIG. 409.—No. 516.—Dam in a shaft formed by an arch of masonry. The masonry should be tolerably thick, and it should be covered by a thick layer of clay well rammed down, so that if a dislocation is caused by a movement of the ground it may be prevented from producing cracks that will let down the water, which the dam is intended to keep up.

The pipe shown in the figure serves to carry off the water until the

work is completed, and the dam allowed to take its load. The kind of pavement above the layer of clay is put in for the purpose of preventing the clay from being softened and washed away at once, if a great crack were formed in the arch extending up through the clay.

Plate LXXVII.—Figures 410 to 415.

Fig 410.—No. **525.**—Hand pump made of wood for use underground, and details of the bucket and clack.

This pump can easily be made even by an ordinary timberman; but as a rule, nowadays, preference will be given to metal pumps more or less like fire-engines, of which there are very many forms.

These metal pumps are more easily carried about and put up; they can be worked at higher pressures and with less leakage, and the workmen are able to apply their power under more favourable conditions.

Fig. 411.—No. **526.**—This figure is merely a sort of diagram intended to convey an idea of the system of flat-rods employed formerly, and still in use in some places, for transmitting the power of a water-wheel to winding or pumping machinery at a distance.

Fig. 412.—No. **526.**—Sundry details relating to the flat-rods of the preceding figure.

An examination of these figures shows how it was possible by means of two parallel lines of flat-rods, acting by traction only, to produce the equivalent of a double-acting connecting-rod, and transmit the power from the water-wheel to the winding-drums or to two coupled main-rods of a system of pumps.

Figs. 413, 414, 415.—No. **527.**—These figures represent three kinds of water-tanks, which are employed when the same engine is used for hoisting mineral and drawing water.

The water-tank shown in figure 413 is run like an ordinary waggon on to the cage. It is filled by a valve opening upwards, and is emptied by means of a leather hose, which lets out the water when it is dropped down.

In figure 414, the tank itself takes the place of the cage. On reaching the *sump* or *fork* it fills itself by a clack in the bottom opening upwards, and it is emptied at the surface by a valve which the *lander* (*banksman*) opens by means of a lever.

The tank shown in figure 415 is emptied automatically by a stop fixed

on the head-gear, which touches the end of a lever connected with the clack.

These arrangements may be greatly varied. Very frequently, for instance, the water-tank is filled and emptied by means of the same valve, which is lifted up by the pressure of the water when the tank dips into the *fork*, and is opened by means of a small iron rod when the tank is *landed* at the surface. (See the text of No. 527.)

Plate LXXVIII.—Figure 416.

Fig. 416.—No. **528.**—This figure, and those of the next four plates, represent pumping engines. In order to facilitate a comparison, they are all drawn on the same scale.

The type shown in figure 416 is somewhat special. Instead of being erected at the surface to work a series of lifts in the shaft, the engine is placed at the bottom, a little above the *sump* or *fork* and works plungers, which force the water to the surface in one column.

In this way the ordinary cumbersome and costly pump-gear is dispensed with; but the machinery and column are exposed to very great pressures, and have to be erected and kept in order with the greatest care.

The advantages of this system diminish with the depth of the mine. (See the text of No. 528.)

Plate LXXIX.—Figure 417.

Fig. 417.—No. **529.**—This figure is an example of the type of pumping engine known as the Cornish engine.

This type of engine, which is defined exactly in No. 529, may be regarded as having reached a high stage of perfection in the economy of steam, and as being thoroughly suitable for heavy pumping.

It is in very general use in England, especially in the metalliferous mines of Cornwall and Devonshire.

With reference to the consumption of coal, no steam-engines in use have given more satisfactory results than the large Cornish engines if *judiciously constructed;* that is to say, if they have been made to work at a high rate of expansion, or, what comes to the same thing, to set in motion *sufficiently large masses, properly balanced.*

These engines are constructed so as to be able to pump slowly. This property, which is of some consequence in helping to keep the engine,

and more especially the pumps and pump-gear, in good order, becomes more and more a necessity as the depth of the mine and quantity of water to be raised increase in amount. (See the numerical data of No. 547.)

Plate LXXX.—Figure 418.

FIG. 418.—No. **530.**—Figure 418 represents the Bull engine, which may be quite as economical as the Cornish engine (at least theoretically there is no special reason for its being inferior), but which differs from it in the manner in which the power is transmitted from the piston to the main rod of the pumps.

Instead of there being a *beam*, the engine works by *direct traction*.

This is the type of engine most commonly used on the Continent. Compared with the Cornish engine, it has the disadvantage of blocking up the top of the shaft to a greater extent, but it has the advantage of costing less to erect.

Plate LXXXI.—Figure 419.

FIG. 419.—No. **531.**—This figure is intended to represent a modification which is applicable to both systems just mentioned. The object of this modification is to apply to single-acting engines Woolf's system of expansion, which is used with much advantage in carefully constructed rotary engines, where economy of fuel is aimed at.

The applicability of Woolf's system to pumping engines was pointed out long ago, and indeed the plan was tried in Cornwall, but these early trials have not been repeated.

The engine represented in the figure is a new trial from which a decided advantage may be expected, less perhaps with respect to economy of fuel, than with reference to smaller strains on the various parts of the pumping machinery, for a given cut-off and a given mass to be set in motion. (See the text of No. 531.)

Plate LXXXII.—Figure 420.

FIG. 420.—No. **532.**—This figure is intended to represent an appliance which may be added to pumping engines, whether *beam* or *direct traction* engines.

This appliance, proposed and used by M. Bochkoltz under the name of *power-regenerator*, is based upon the fact, that the weight required *to*

raise the top-clack of a force-pump is considerably greater than the weight required for forcing only, when once the valve has been raised.

It is therefore necessary to give the main-rod an excess of weight, which is of no further service during the latter part of the stroke, and is consequently injurious, as it entails a pure loss of power when the main-rod has to be raised again.

The power-regenerator enables us to produce the supplementary force required at the beginning of the downstroke without any expenditure of work, because it simply has an oscillating motion like that of a pendulum. It is easy to see that, independently of this advantage, it allows the engine to be worked more quickly. For a given quantity of water to be raised, it enables us to use a smaller engine; or else, where an engine has already been erected, it renders that engine capable of coping with a larger quantity of water.

To sum up the information given in the explanation of Plates LXXIX. to LXXXII., we may say that the best type of large pumping engine at the present day is either the single-acting Cornish or the direct traction engine, with two cylinders on Woolf's system, and a Bochkoltz regenerator.

The larger the size of the pumping machinery the greater is the reason for adopting this system.

The other systems mentioned in Nos. 526 to 528 appear to be simply applicable to cases where the amount of water and the depth of the workings are not too great.

Plate LXXXIII.—Figures 421 to 428.

FIG. 421.—No. **533.**—Diagrams for explaining the modes of action of various kinds of pumps.

An arrow in each of the diagrams A, B, C, D, denotes the direction in which the piston is supposed to be travelling, and the valves are represented as closed or shut accordingly.

A. Lifting pump with hollow piston.

B. Lifting pump with solid piston.

C. Lifting pump with plunger.

D. Forcing pump with plunger.

FIG. 422.—No. **536.**—General sketch and details of a *drawing lift* fixed at the bottom of a series of pumps.

The figures represent the principal details mentioned in the text of No. 536.

FIGS. 423 and 424.—No. **536.**—Details of clacks and buckets.

Figure 423, which is supposed to represent a tolerably large clack, shows a different arrangement from the *butterfly clack* where the two semicircular valves are hinged along a diameter; in this figure there are several valves opening towards the centre. This plan affords a freer passage for the water which has to pass through.

Figure 424 shows a form of bucket which is very suitable for large pumps where the water is full of grit, such as that met with in sinking through very watery strata.

FIGS. 425 and 426.—No. **537.**—Two modes of arranging a plunger pump.

In figure 425 the upper part of the plunger-case may contain air sucked in during the upstroke. In order to reduce the diminution in the delivery which would be caused by this cushion of air, it is necessary that the plunger should fill the case as nearly as possible.

In figure 426 this cushion of air cannot exist; but with this arrangement the plunger-case requires to be made very decidedly larger than the pole, so that there may be no difficulty in forcing the water into the rising main. We may also notice in this figure an arrangement for connecting the top and bottom clacks so as to ensure their being kept in their seats.

FIGS. 427 and 428.—No. **539.**—These two figures explain modes of joining the pieces of timber forming a main-rod.

In figure 427 we have strapping-plates and bolts; whilst in figure 428 there are two large cleats held together by staples and glands as well as by pins connecting each cleat with the main-rod. This system is, perhaps, preferable to the former, as the fibres of the wood are not cut through so much as with strapping-plates and bolts.

Plate LXXXIV.—Figures 429 to 435.

FIGS. 429, 430, and 431.—No. **539.**—These three figures represent various modes of connecting a bucket-rod or a plunger-pole to the main-rod.

The method shown in figure 429 is best adapted for the bucket-rod of a drawing-lift. That of figure 430 is applicable to any kind of pump; whilst the arrangement represented in figure 431 is specially suitable for force-pumps.

This last system has the advantage of causing the reaction exerted by the water at the base of each plunger during the down-stroke to be

brought into line with the axis of the main-rod. This system merely amounts to this, that the main-rod is greatly enlarged in one place, and a kind of mortise is left, which encloses the bearers and the plunger-case; the length of the mortise being rather greater than that of the stroke of the pump.

FIGS. 432 and 433.—No. **539.**—Main-rods constructed of iron or steel.

These metallic rods may be made of various shapes, and in making our choice we must be guided by the principles relating to the resistance of materials.

In order to resist tension they must be made of a sufficiently great section.

In order to resist compression, and diminish vibratory movements, this section ought to have *the greatest possible moment of inertia* with respect to an axis situated in its own plane, and passing through its centre of gravity.

The section adopted will be that of a connecting-rod (fig. 432 A), or of a thin hollow pipe (fig. 432 B), or longitudinally that of a lattice-girder (fig. 433), &c.

FIG. 434.—No. **540.**—Balance-bob intended to balance part of the excess of weight of the main-rod over the weight of the column of water forced up by the plunger during the down-stroke. With small pit-work and deep shafts this excess exists naturally, and if necessary in other cases it can be created artificially by loading the rod.

Figure 434 shows a good balance-bob, which may be easily erected anywhere in a shaft by cutting out an excavation in the side (*bob-plat*).

The beam may also be constructed of cast or wrought iron, like that of a steam-engine.

FIG. 435.—No. **542.**—Steam capstan for putting pumps into a shaft.

This machine is practically a true double-cylinder winding-engine, and consequently can be worked just as easily as one of these. It is very convenient for putting in heavy pumps or rods, and it is not taken down after the pitwork has been put in, but is left for use in heavy repairs, which are frequently necessary.

Plate LXXXV.—Figures 436 to 439.

FIG. 436.—NOS. **543** to **546.**—This and the other figures of this plate refer to draining shafts while they are being sunk through very watery strata.

Figure 436 gives a plan and section of a pit lined with tubbing with the great bearer placed at the surface, from which the pumps are hung; they are lowered gradually, as the pit is deepened, by means of large screwed bolts (*lifting-screws*).

Fig. 437.—Nos. **543** to **546**.—Plan and vertical sections of a pit lined with tubbing, and of the cistern fixed to the tubbing, which carries the windbore of the upper-lift. This arrangement is always adopted when it is thought probable that the thickness of the water-bearing strata will exceed 50 yards.

Fig. 438.—Nos. **543** to **546**.—Mode of suspending a drawing-lift by means of chains.

Fig. 439.—Nos. **543** to **546**.—Details concerning a large pump for sinking through watery strata. The figures represent the working-barrel, the bucket like that of figure 424, the *yokes* and the rods for suspending the pump.

Plate LXXXVI.—Figures 440 to 448.

Fig. 440.—No. **563**.—This figure and those following it refer to the ventilation of mines. Fig. 440 is a simple geometrical diagram, representing the case of a mine with horizontal workings, and with two shafts of equal depth. In the kind of siphon thus formed the air-current has no tendency to draw either in one direction or the other. But if any external force tends to determine it in one sense or the other, the same cause serves to maintain it, and that with a greater degree of intensity than at the outset in winter, and with a less degree of intensity in summer. (See the text.)

Fig. 441.—No. **563**.—In this case it is supposed that the mouths of the shafts are at the same level, but that they are of different depths; that is to say, that the workings are inclined.

For several reasons the current will usually flow from the pit B towards the pit A, because the air in the inclined branch C D will usually be lighter than that in the corresponding portion C*d* of the vertical branch B C, whilst the two portions, B*d* and A D, may be considered as equivalent to each other.

Fig. 442.—No. **563**.—Here we have the mouths of the two shafts at different levels. It will be easily understood that the air-current will

flow from the lower towards the higher pit in winter, and that it will flow in the opposite direction in summer.

Fig. 443.—No. **565.**—This figure shows how the difference of level, referred to in the preceding figure, can be created artificially by means of a chimney, although the mouths of the two shafts may be in the same horizontal plane. It must be admitted, however, that this chimney will be much less efficacious in the case of the summer current than in the case of the winter current.

Fig. 444.—No. **567.**—This figure represents a fire-basket, in which a coal fire is maintained. It can be placed at the base of the chimney of the preceding figure, or hung a short distance down the shaft by means of a windlass and chain. The draught of the chimney is increased in this manner.

Fig. 445.—No. **567.**—Figure 445 and the two succeeding ones refer to artificial ventilation by means of ventilating furnaces. These furnaces are much more powerful than the fire-baskets, both in consequence of the greater amount of fuel consumed in them, and of their more favourable position, *which is at the point where the air-current reaches the bottom of the up-cast shaft after it has passed round the workings.*

Figure 445 represents, both in plan and section, a large furnace with two fire-grates built in a cross-measure drift, which serves as a return air-way, and communicates with the up-cast shaft by a short passage (*furnace-drift*).

Fig. 446.—No. **567.**—This figure represents the furnace built in one of the ordinary galleries in the coal. In this case it is necessary to isolate the furnace entirely, so as to avoid the chance of setting the coal on fire; and this is effected, as the figure shows, by building two concentric arches, between which there is a passage for air.

Fig. 447.—No. **567.**—In this case the furnace is placed in a special excavation, in which it is isolated as well as possible from the air-current, which has passed round the workings, and which may possibly become charged with fire-damp to the explosive point.

The furnace is fed by a special current of air coming directly from the surface.

Figure 447 represents the system adopted in the Department of the Nord. The special current which feeds the furnace is brought down through the dead measures by a special compartment bratticed off from the main shaft. After the coal-measures are reached it is conveyed down through a series of *staples* and galleries, following the inclination of the seam, until it reaches the furnace. (See the text of No. 567.)

FIG. 448.—No. **570.**—This figure is intended to show that blowing machines employed for ventilating mines have a slight theoretical advantage over exhausting machines from a mechanical point of view. (For a discussion of this subject, as well as the bearings of the advantage referred to, see the text of Nos. 570 and 571.)

Plate LXXXVII.—Figures 449 to 451.

FIG. 449.—No. **575.**—This figure, and those that follow it as far as figure 468, are devoted to the illustration of ventilating machines.

Figure 449, which is copied from *La richesse minérale*, represents one of the first ventilating machines employed. It is a kind of gasometer, which exhausts when it is raised, and blows when it is lowered. It is supposed to be actuated by one of the main-rods of the pumps.

FIG. 450.—No. **575.**—A diagram representing the modification of the previous apparatus that can be introduced if it is desirable to make it double-acting. It is simply necessary to impart an oscillatory movement to the beam represented in the figure.

FIG. 451.—No. **575.**—This figure represents a machine identical as regards its principle with the one shown in the preceding figure, but different in construction

These machines, known as Struvé's ventilators, were a good deal in favour in Belgium about thirty years ago, when mechanical ventilators first began to be used on a large scale.

One of the bells is represented in elevation, the other, half in elevation, half in section. This part of the figure shows how the valves for exhausting and expelling the air are balanced in such a way that their play demands only a slight pressure on either of their faces.

Another important improvement will be observed; namely, that the hydraulic water joint is reduced to a simple ring, thus giving the opportunity of making the exhausting passage of very large diameter.

FIG. 451 *bis.*—No. **575.**—A diagram representing a triple machine, whose three bells are actuated by cranks keyed on to the same shaft at angles of 120°. This arrangement tends to regulate the exhausting action in the gallery which leads from the shaft.

The same figure shows also the safety arrangement of M. Devaux, referred to at the end of No. 573, the object of which is to give a free passage to the ventilating current without delay, in the event of the ventilator being stopped accidentally.

Plate LXVIII.—Figure 452.

FIG. 452.—No. **575.**—An exhausting machine or air-pump, composed of two single-acting cylinders, which are simply wooden tubs with pistons working in them. The employment of wood in this case is perfectly justifiable, since the pressures differ so slightly from that of the atmosphere.

The transmission of power from the steam piston to the piston rods of the ventilating machine is effected in a simpler manner than by parallel motion, and in such a way that these cylinders can be separated as far as we like. The cylinders shown in the figure are forty feet apart, which allows of the boilers being placed between them, and in close proximity to the steam cylinder.

Plate LXXXIX.—Figures 453 to 456.

FIG. 453.—No. **575.**—An exhausting piston machine of the same kind as the last, but the mechanical arrangements are less fit for being applied on a large scale.

It will be remarked that all the valves are balanced, as in the machine represented in figure 451.

FIG. 454.—No. **575.**—Diagram of another exhausting piston machine, called Nixon's ventilator, employed in England. It differs from the preceding ones, firstly, in having only a single chamber, which is double-acting; secondly, the piston moves horizontally instead of vertically, and lastly, both the inlet and outlet valves beat against vertical seats.

The result is that the valves open very easily, but it requires a sensible manometrical depression to keep them wide open. This arrangement appears therefore to be less satisfactory than that of having balanced valves.

FIG. 455A and 455B.—No. **575.**—These two figures, and those which follow them as far as figure 462, represent ventilating machines of the second of the categories mentioned in the text of No. 575.

FIG. 455A represents the Letoret fan, which was one of the first of the kind that was constructed. The figure shows the method adopted for regulating the angle of the vanes experimentally.

FIG. 455B shows the vanes set at a fixed angle, and the stays by which they were connected.

These two systems have the same common drawback; namely, the great distance between the vanes at the circumference, which causes injurious re-entrances of air, and eddies. (See the text of No. 577.)

Fig. 456.—No. **575.**—Plan and vertical section of an exhausting fan with curved vanes, proposed by M. Combes.

This ventilator differs from the Letoret fan in that the axis is vertical (although this is not a necessary condition). It has also a hydraulic joint for the purpose of preventing the escape of air between the vanes and the fixed surfaces; and lastly, the curve of its vanes is different.

The object of the curvature is to reduce the absolute velocity of the air at the point of escape, by giving it a relative velocity in a contrary sense to that of the velocity with which it is carried round.

This machine was not sensibly superior to Letoret's, because there were the same abnormal movements of the mass of the air due to the wide spaces between the vanes. (See, as above, the text of No. 577.)

Plate XC.—Figures 457 to 459.

Fig. 457.—No. **575.**—This is an apparatus known by the name of the pneumatic screw. We must suppose that the air contained in the space between the axle of the screw and the fixed casing is impelled in the direction of the axis by the action of the screw, and that there is thus an exhaustion produced at one end or the other, according to the direction in which the screw revolves.

This machine may be sufficient when only slight depressions are required. Otherwise it is easy to see that the air would be expelled along the sides of the fixed envelope or casing; but, at the same time, that there would be a tendency to produce re-entrances of air in the form of eddies around the centre.

Fig. 458.—No. **575.**—This is another arrangement of the air-screw, in which the axle is placed horizontally.

If we neglect the position of the axle, which is a matter of no importance as regards the working of the machine, the latter is less favourably circumstanced than the former in consequence of the small diameter of the axle.

As the air is always more or less drawn along in the rotatory movement of the screw, it is easy to see that the air has a tendency to be condensed on the exterior of the helix, and to be rarefied along the axle in consequence of the centrifugal motion imparted to it. This, of course, favours re-entrances of air.

FIG. 459.—No. 575.—The machine shown in figure 459 is known by the name of the ventilator with windmill vanes, or Lesoinne's ventilator.

In the form shown, its action is the same as that of the air-screw, and, like the latter, its axle is very small. It does not appear suitable for working with considerable depressions, and it has not been employed extensively.

Plate XCI.—Figures 460 to 462.

FIG. 460.—No. 576.—Guibal's fan. This is a centrifugal ventilator, the first idea of which was taken from Letoret's fan. (Figure 455.) It has been essentially perfected, in the first place, as regards the construction of the vanes; in the second place, by the addition of an envelope or casing, which prevents re-entrances of air; in the third place, by a movable shutter, whose position is regulated experimentally; and fourthly and lastly, by the trumpet-shaped chimney, which reduces the velocity of the air before it escapes into the atmosphere.

Modified in this way, Guibal's fan is very superior to all the other ventilators of the second class described above (figures 455 *et seq*). (See the text of Nos. 576 and 577.)

FIG. 461.—No. 576.—Figure 461 represents a Guibal fan very similar to the one shown in the preceding figure, but with the following modifications:

In the first place, the tips of the vanes have been made slightly concave, and it will be remarked that this concavity is in the opposite sense to that given by M. Combes. The reason of this is that its object is totally different. M. Combes sought to obtain as small an absolute velocity as possible at the point of expulsion. M. Guibal had no object in seeking this result, since his widening chimney utilized this velocity. He seeks to furnish the greatest possible volume of air; and in giving the points of the vanes a radial direction, he tries to impart to the air the same velocity as that of the periphery of the fan.

In the second place the machine is capable either of exhausting or blowing the air, the rotatory motion being continued in the same sense. An inspection of the figure will make the arrangement clear, although it can be modified in various ways. When the fan is intended to exhaust, the central canal is placed in communication with the interior of the mine and the circumference with the chimney; when it is intended to blow, the central opening communicates with the exterior, and the chimney terminates in a passage which carries the air to the mine.

FIG. 462.—No. **578.**—Harzé's ventilator. This ventilator is similar to Combes' (figure 456) as regards the position of its axis, the employment of a water-joint, and the care taken to direct the air when it enters the apparatus.

It differs, however, in so far that the vanes, instead of terminating tangentially at the circumference, are nearly at right angles to it, or are almost radial, like those in Guibal's ventilator.

It differs besides from the last by the employment of the *diffuser.* This is in reality a series of fixed channels through which the air has to pass; they widen outwards, and serve the same purpose as M. Guibal's chimney. When well designed this ventilator appears to be of about the same value as Guibal's fan, although it is perhaps not capable of producing such great depressions of the water-gauge. (See the text of No. 578.)

Plate XCII.—Figures 463 to 465.

FIG. 463.—No. **579.**—This figure and those that succeed it as far as figure 466, refer to machines of the third category mentioned in No. 575. These machines are distinguishable from those of the second category by two characteristics, firstly, of giving always a calculable quantity of air per revolution, independently of their velocity and of the manometrical depression; and secondly, of being able to produce any amount of depression that may be required.

The second characteristic renders them very appropriate for application in mines where the ventilation is difficult in consequence of the small section or great development of the galleries.

Figure 463 represents Fabry's ventilator or air-wheel.

This machine, for the theoretical properties of which we refer to the text of No. 579, is very applicable to mines in which a great volume of air is not required, but a considerable depression of the water-gauge.

By simply reversing the direction of rotation, it can be changed from an exhausting into a blowing machine at pleasure.

FIG. 464.—No. **581.**—The machine shown in this figure is Lemielle's ventilator, or air-drum. It has undergone several modifications of form, and it has all the essential properties of Fabry's machine.

It differs from the latter in being more complicated in its details and stronger in its mode of construction. It has to be attended to rather more carefully, but it can be made of much larger dimensions, and be driven at velocities which enable it to deliver a much larger volume of air

It is suitable for ventilating mines which require *both a large volume of air and a great manometrical depression.*

The inlet and outlet orifices are placed in such positions that the edges of two consecutive vanes are at one and the same time at b and b', or at b_1 and b_1'.

FIG. 465.—No. **581.**—This figure and the one following it represent Lemielle's ventilator and the details of its construction, the preceding figure being simply a geometrical diagram. In these figures we notice the various arrangements that can be made for the purpose of preventing escapes of air, both at the upper end of the movable drum, which carries the vanes, and at the openings in the drum itself, through which the connecting rods pass, which move the vanes backwards and forwards upon their hinges.

Plate XCIII.—Figures 466 to 468.

FIG. 466.—No. **581.**—(For a description of this figure see the account of figure 465.)

FIG. 467.—No. **584.**—Water-blast apparatuses are not often applied to the ventilation of mines, but at one time were used for blowing certain metallurgical furnaces, and especially the Catalan forge.

The action of these water-blasts is based on the fact that falling water drags the surrounding and entangled air along with it, producing an exhausting effect, when the air can only enter by certain properly-arranged orifices.

The kind of froth formed by the mixture of air and water strikes upon a flat surface or table, which causes it to splash off in the form of drops, and in this way sets free the imprisoned air.

This system may be looked upon as very unfavourable for the utilization of the work of a given fall of water; but a water-blast of this kind is easily put up, and requires no special machine to drive it.

FIG. 468.—No. **584.**—This machine, which was proposed by M. Guibal, is intended to produce a movement of translation in the mass of air by means of a kind of Archimedean or Dutch screw, the axis of which is placed horizontally.

This system, which is based upon a very simple idea, has the disadvantage of setting in motion uselessly, or rather with a very considerable loss due to friction, the mass of water in which the lower portion of the axle and the surface of the screw are immersed.

Plate XCIV.—Figures 469 to 479.

Figs. 469 to 472.—No. **588.**—Examples of various arrangements that can be made for ventilating an advanced gallery or *end*.

Figure 469 represents a compartment partitioned off by a more or less air-tight brattice. The brattice is often vertical, or nearly so; but if the gallery is high enough the brattice may be set up horizontally (*air-sollar*, Cornwall), so as to form a return air-way in the roof of the gallery, and then it may be rendered more air-tight by covering it with a certain thickness of powdery rubbish.

Figure 470. In this case the brattice consists of a small segment of an arch one brick or half a brick thick.

Figure 471. Here the section of the gallery is supposed to be very small, and the air-compartment is formed by means of sheet iron or zinc pipes joined end to end, and fixed in a simple and substantial manner in one of the higher angles of the timbering. If the top of the gallery is very narrow the pipes are sometimes placed on the ground in one of the angles, between a sole-piece and a *leg* of a frame of timbering. Simple square wooden boxes are sometimes used instead of the metal air-pipes.

Another arrangement frequently employed (fig. 472) consists in having two parallel drifts, instead of a single one. These are placed in communication from time to time by cross-cuts, which are stowed up successively as soon as a new one is opened.

It is easy to understand how the air-current can be compelled to go to the face of one or other of the galleries in case of need when the current is at some distance from the face. A door, or a stopping, and a line of pipes passing through it, solve the question.

Fig. 473.—No. **588.**—The two figures 473 A and 473 B represent the arrangement that can be made at a point where two galleries cross each other when it is requisite to isolate the current of air passing along one of them from that passing along the other.

Figure 473 A represents the case in which room for haulage, or at any rate for the free passage of men, has to be reserved in both galleries. The isolation is then obtained by means of doors set up in a part of the gallery in which the roof has been taken down. The doors are made single or double, according to the importance of preserving complete isolation between the two galleries or not.

Figure 473 B supposes that the gallery that has been heightened does not require to be traversed.

Fig. 474.—No. **599.**—Ordinary lamp like an antique lamp.

Fig. 475.—No. **599.**—Ordinary miner's lamp, *turnip-shaped*, employed

in the mines of the department of the Loire. This lamp is strongly made of wrought iron, and is carried by means of a handle provided with a hook, which serves to hold it in the hand, and to fix it to the timber by driving the point of the hook into one of the props. It is also often provided with a small pin, which serves the purpose of raising and trimming the wick.

FIG. 476.—No. **599.**—A lamp used in the mines of the department of the Nord, and very convenient for carrying on ladders or in low galleries. It can either be carried in the cap or held by the handle, and, like the preceding lamp, it can be fixed to the timber by driving the point into a prop or cap.

FIG. 477.—No. **600.**—Dumas' portable electric lamp, which can be employed in working-places in which ordinary lamps will not burn for want of air, or cannot be employed owing to the presence of fire-damp. (See the text of No. 600.)

FIG. 478.—No. **605.**—Ordinary safety or Davy lamp employed in those mines, or districts of mines, in which the presence of fire-damp is feared.

Its safety depends on the wire-gauze cylinder which surrounds the flame. If any fire-damp has become ignited from the flame inside the lamp, the burning gases are so cooled down by their passage through the small meshes as to be no longer incandescent. The combustion of the gaseous mass cannot thus be propagated outside the wire-gauze cylinder, at least as long as no circumstances arise to cause the wire-gauze itself to be heated to incandescence, or to drive the burning gases so quickly through the gauze that they do not become sufficiently cooled.

The safety of the Davy lamp is thus not absolute. This lamp will most usually prevent such explosions as would arise from the accidental contact of the flame of a lamp with an explosive mixture of fire-damp and air; but it cannot be considered safe to work with it in such a mixture. (See the text of No. 605.)

FIG. 479.—No. **606.**—Mueseler's safety lamp. Amongst the numerous proposed modifications of the Davy lamp, which however is still more frequently employed than any other at the present day, the Mueseler lamp is the one that has come into most general use, and especially in Belgium.*

It gives a better light than the Davy lamp; it is safer in explosive mixtures, but it has the drawback of being too easily extinguished under various circumstances. (For more details see the text of No. 606.)

* In England the Clanny lamp is more commonly employed than the Davy lamp; but the Mueseler lamp is gradually coming into use.—*Translators.*